CHNOLOGY DEPT

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Plastics

DEALING WITH THE MANUFACTURE, USES AND POTENTIALITIES OF PLASTIC MATERIALS

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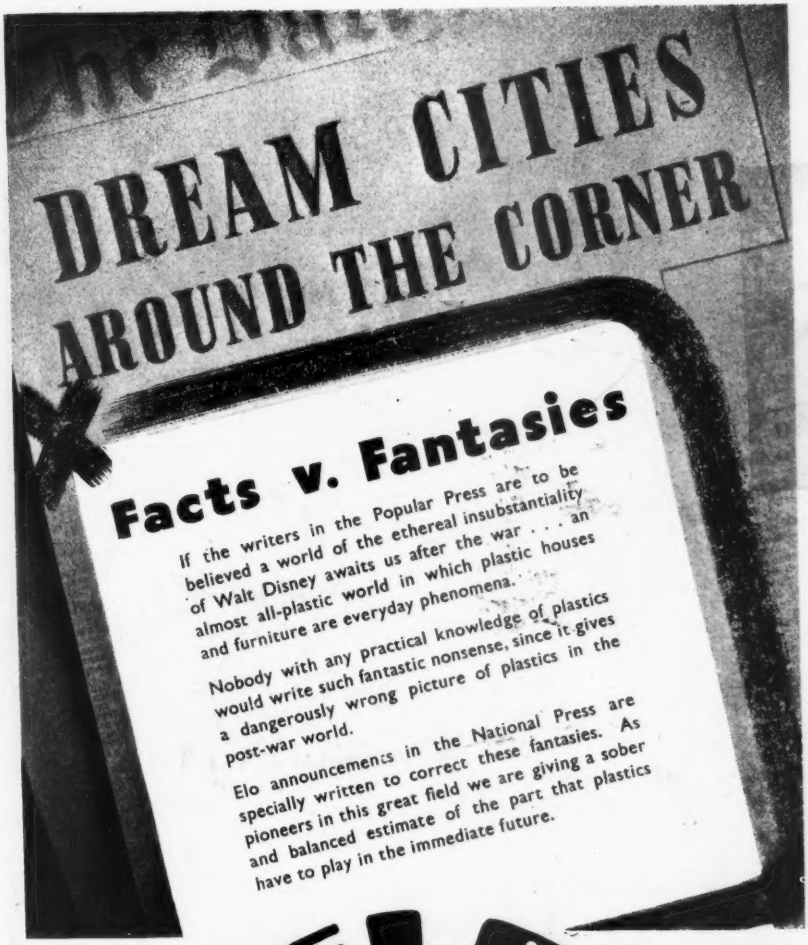
DREAM CITIES
AROUND THE CORNER
Facts v. Fantasies
If the writers in the Popular Press are to be believed a world of the ethereal insubstantiality of Walt Disney awaits us after the war . . . an almost all-plastic world in which plastic houses and furniture are everyday phenomena.
Nobody with any practical knowledge of plastics would write such fantastic nonsense, since it gives a dangerously wrong picture of plastics in the post-war world.
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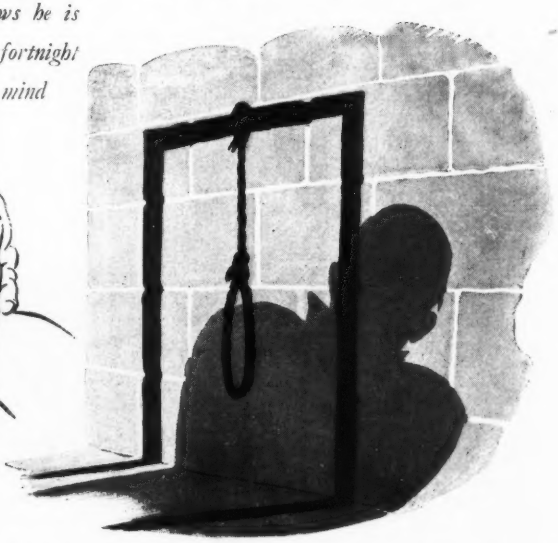
"Depend upon it sir," said DR. JOHNSON, "when a man knows he is to be hanged in a fortnight it concentrates his mind wonderfully"



Who is going to hang after this war? We are fighting to escape the gallows which Nazi fanatics and Co-Prosperity fiends were making ready for British Industry and Trade. Our minds are consequently, and rightly, "concentrated wonderfully" on war production. But are you, on your part, also ready to reap the benefits of many advances made in methods of production and in the use of new raw materials? Are you acquainted with the many new uses of "PAPER" in industrial processes? We can help you in this.

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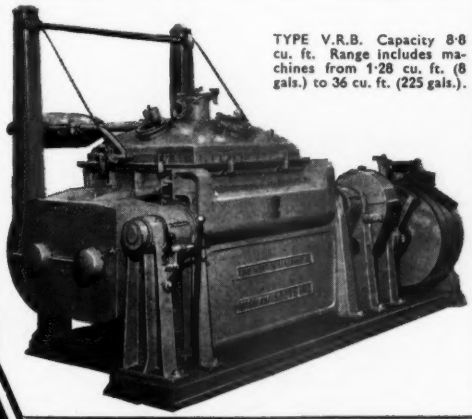

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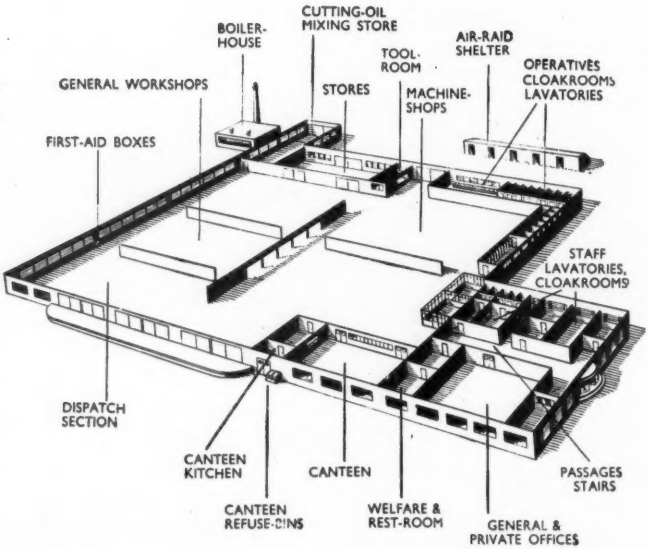

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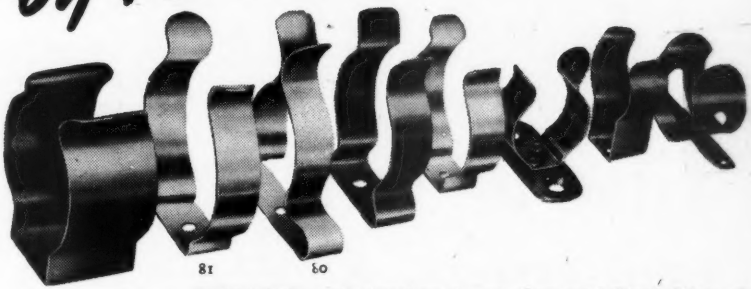

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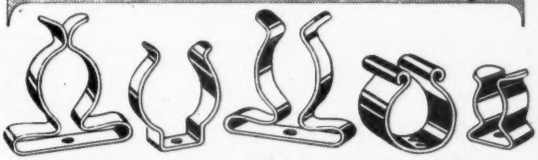

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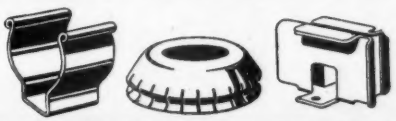

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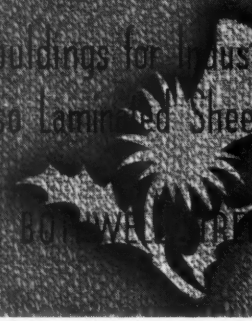

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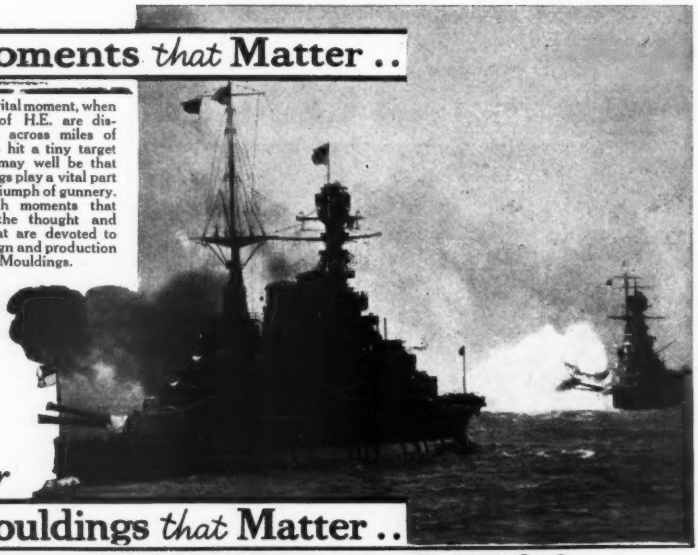

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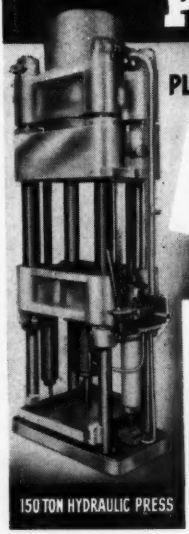

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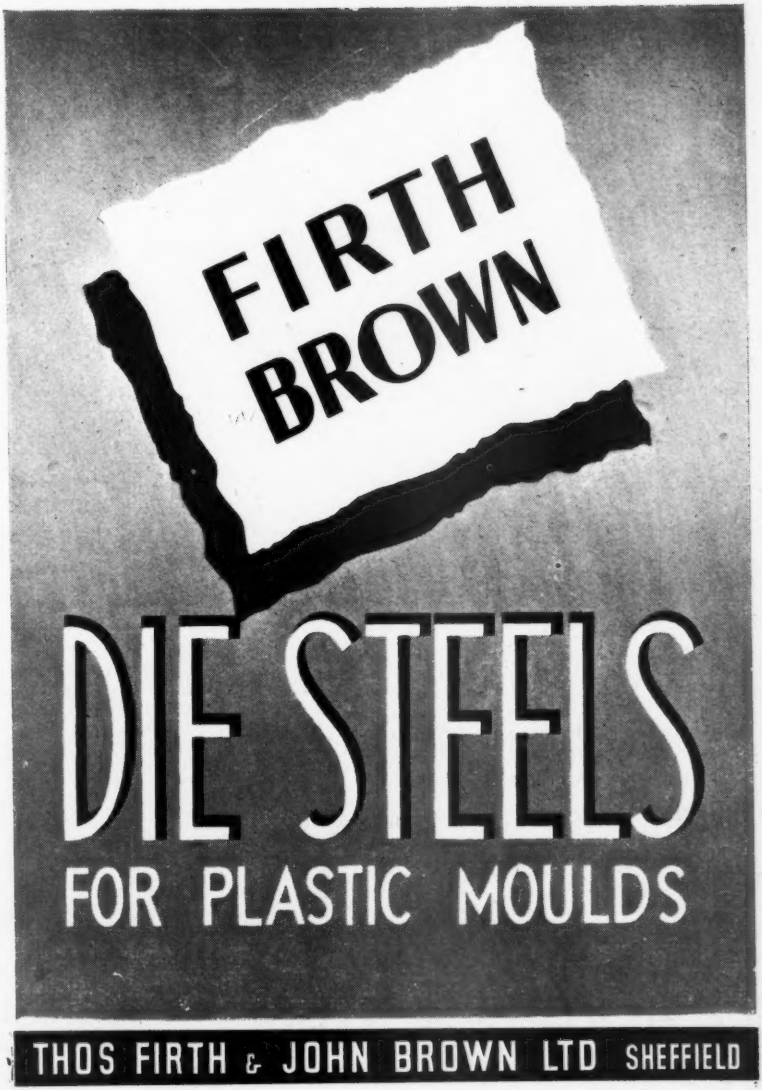
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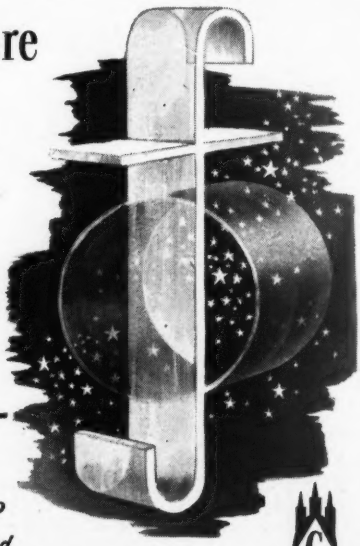

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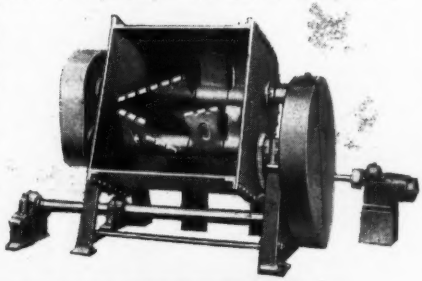

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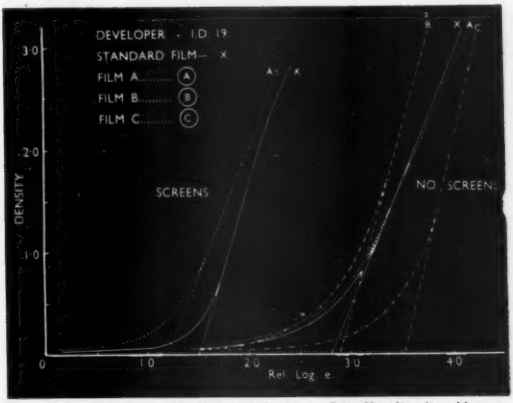
FOR INDUSTRIAL RADIOGRAPHY



The diagram above shows the characteristic curves of the films listed on this page in comparison with Ilford Standard X-ray film used in medical radiography

THE need of Industrial Radiography to-day is for a range of sensitised materials varying in their characteristics according to the work to be done. Ilford Limited have met this need with 3 distinct types of X-ray films which, as will be seen from the descriptions opposite, fully cover every requirement.

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A slow, fine grain, high contrast film for the detection of the finest detail in light structures, or in thin sections of heavier materials, which can be easily penetrated.

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INDUSTRIAL X-RAY FILMS

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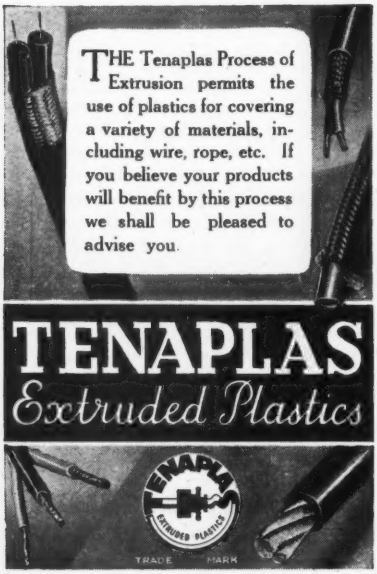

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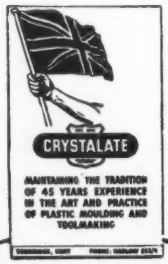
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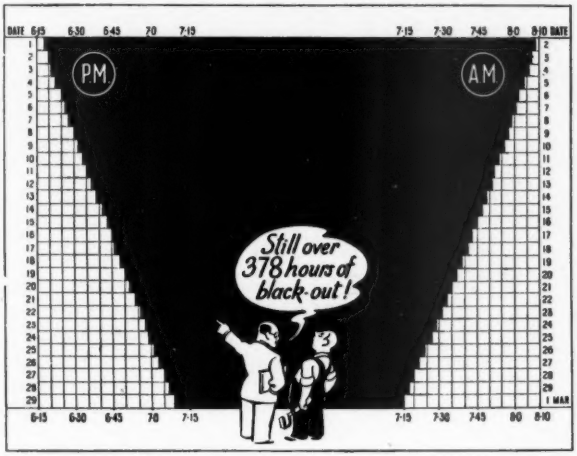
The Turn of the Tide

BLACK-OUT CHART FOR FEBRUARY



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**Times shown are those for the London area.*

It is in February that already we feel the approach of spring. Better weather is ahead, the dark days of winter are receding. In the industrial field, February heralds the narrowing of the black-out chart, but during the shortest month, however, blinds must be drawn for over 378 hours.

Good lighting is still of the greatest importance in keeping up spirits and keeping down strain and fatigue. Osram can do much to help.

Osram

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FOR EVERY APPLICATION

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The moulding illustrated is by courtesy of George Kent Ltd., Luton.

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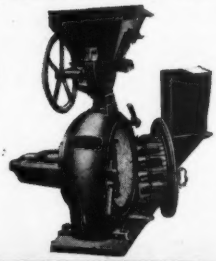

THIS GARDNER "Rapid" Combined Grinder and Sifter does both operations simultaneously, often dispensing with a separate dressing machine. Fitted with interchangeable screens, every part is accessible for cleaning quickly and easily. Like all GARDNER plant, upkeep is virtually nil and it will run for many years without overhaul or maintenance. If required, can be supplied direct coupled to motor.

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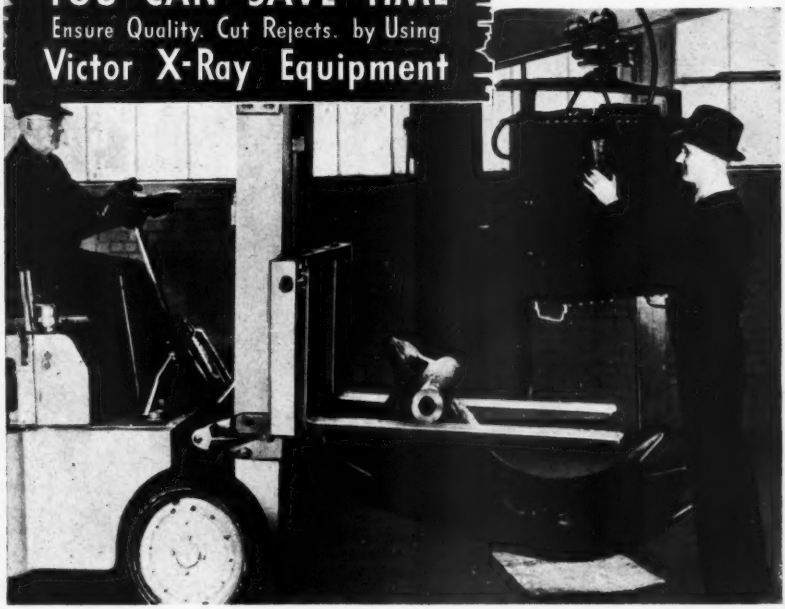

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Vol. VIII. No. 81 FEBRUARY, 1944

Plastics

Dealing with the Manufacture, Uses and Potentialities of Plastic Materials

Proprietors - - TEMPLE PRESS LIMITED
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NOTICES

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SAVE PAPER

More than ever is paper waste required for our war industries. Waste paper makes munitions in a hundred forms—from shell cases to aeroplane parts.

The fact that goods made of raw materials in short supply because of war conditions are advertised in this journal should not be taken as an indication that they are necessarily available for export.

EDITORIALS

Chemical Trusts and the War Effort

DURING the last few months the attention of the world has been drawn very violently by American authorities and economists to the workings of the so-called chemical trusts and cartels, and more especially to the two famous chemical companies, Du Pont de Nemours of U.S.A. and I.C.I., Ltd., of this country, which have been accused of being organizations detrimental to the welfare of the U.S.A., and, by implication, to the welfare of this country.

The public, in a vague sort of way, know of the existence of anti-trust laws in the U.S.A., and, in an equally vague way, why large concerns, trusts and the cartels arranged between them, are considered dangerous, the suggested reasons ranging from maintenance of high prices, the ability to crush small businesses, the misuse of patents, and so on. Doubtless trusts, or monopolies, or even medium-sized concerns have behaved and do behave in inimical ways. Unwritten industrial history is presumed to contain many examples; unfortunately, such a history by authoritative unbiased opinion has never appeared in print. Until real facts are before us armchair critics had best remain silent.

Speaking at the Glasgow Chamber of Commerce on February 1, Lord McGowan delivered his " apologia pro vita I.C.I." To most scientists and technologists no " apology " is necessary, for the role I.C.I., Ltd., has played during the past 15 years or so in peace and in war is clear cut. The benefits that have arisen by its formation are truly immense. One of the painful reflections is that most of the criticisms arise through ignorance of industry, and in this special branch through ignorance of chemical science as applied to industry.

Lord McGowan prefaced his remarks by indicating that I.C.I., with its peace-time employment of 70,000 people and 120,000 war-time employees, was small compared with the I.G. of Germany, which employed three times these numbers, or the U.S. firms like United States Steel and General Motors—each of these dwarfed I.C.I. In any event, I.C.I.'s size was not the result of a desire for self-inflation, but of a process of natural and healthy growth.

I.C.I.'s war effort, he said, started in 1935. For some years previously it had conducted research on the extraction of oil from coal at a cost of no less than £1,000,000. In 1935 the company decided to erect, at a cost of nearly £3,000,000, a large plant to produce petrol from British coal and tar. That decision was carried in the face of strong opposition in Parliament and from the Press. I.C.I. was then accused of gambling with shareholders' money, and of wasting money and energy by making something which could be brought from overseas much more cheaply. What had happened? Before the war that plant gave much new employment at a time when unemployment was rife. It used British coal to make motor spirit instead of this being imported. Its operation afforded technical experience which was very valuable when applied to other products. From the national aspect, it was vital. It enabled I.C.I. to place all its information regarding the production of motor and aviation spirit at the disposal of the Committee of Imperial Defence in 1937, and to play the leading part when, in 1939, the Air Ministry decided to erect a new plant to produce the special fuel needed by the Royal Air Force. Nowhere else in the Empire were there men with experience of the hydrogenation process, consequently not only did the major responsibility for the design and erection of the Government plant fall to I.C.I..

but it was to-day managed by I.C.I. This had naturally involved the transfer of a considerable number of expert staff and workpeople, thus throwing added burdens on those remaining at the original plant.

The decision I.C.I. took in 1935 had meant that Britain had been able throughout the war to rely on hundreds of thousands of tons of the highest-grade aviation spirit manufactured in this country. "**I ask you,**" said Lord McGowan, "**what State department, what body of Civil Servants, what Ministers in Parliament would have dared to take the commercial risk involved in the decision which private enterprise took in 1935? Or, in the unlikely event of their daring to do so, what chance would there have been of getting it through Parliament, which would criticize the venture on every ground, and not least that it was an unjustifiable risk of public money?**"

We report this last sentence verbatim, for it points clearly to the methods of efficient private enterprise and those of State ownership. It also points clearly to the ability of large-sized organizations alone to attempt such researches.

With our experience of the carbide muddle and the Severn scheme mess before us, we can well ask ourselves what would State "enterprise" have done?

Lord McGowan described the contribution I.C.I. had made to the war effort in the erection of war factories and as a large reservoir for trained scientific and technical personnel for managing large-scale operations. There were 2,500 I.C.I. senior staff and key men in such posts. This was not done to influence Ministries, as has been fancifully suggested, but because the State needed them in the Ministries of Supply, Aircraft Production and Economic Warfare.

I.C.I.'s peace-time work on the production of silage had resulted in the production of 1½ million tons for the farmer, and the company had developed a process for producing a nourishing cattle food from straw, which is now being used on 3,000 farms.

Explosives, new paints and new methods of painting war machines, new drugs and medicines (I.C.I. will have produced 1,000,000,000 tablets of Mepacrine for the treatment of malaria during 1944), chemical devices for heating cans of soup for the troops in the field, the production of nylon in this country by arrangement with Du Pont de Nemours, the discovery and production of polythene, the outstanding British polymer, the full story of which has yet to be told (I.C.I. have long been pioneers in the field of high-pressure chemistry)—all these and many secret devices and weapons have been the issue of a very virile industry which, we suggest, has received the trust of the Government.

Our Own Opinion

OUR own opinion on all large concerns, which to us means anything with more than £5,000 capital, is a nice sanctimonious hypocritical "There, but for the grace of God, go I." We are all trying to be I.C.I.s, and if we fail we suddenly become quite pious about it.

If Lord McGowan wishes to tell the full story he should go back much farther than 1935.

Many years ago the number of large chemical factories in this country was very small. Before 1914 there had been no real dyestuffs industry here at all and Germany was all powerful and growing fast. Great Britain had no power to oppose Germany in the chemical field and no voice in international chemical affairs.

In 1926, when I.C.I. was born from the union of Brunner Mond, Ltd., United Alkali, Ltd., British Dyestuffs Corporation, and Nobels Explosives, most of us onlookers sighed with relief.

We do not think the country has been the loser.

Federation Reorganization

THE virility of the British Plastics Federation was reflected in the resolutions passed at a recent meeting at Kingsway Hall, London, which recom-

mended the increase of the general subscription of members to the funds of the Federation from 10 to 15 guineas as from January 1, 1944, and a reorganization of the Federation.

The reorganization is considered under the following headings:—

1. An increase in the revenue of the Federation.
2. The formation of the following Groups having a large measure of autonomy:
   - A. Plastics Material Manufacturers' Group.
   - B. Moulders' Group.
   - C. Fabricators' Group.
   - D. Engineers' Group.
   - E. General Members' Group.
3. Reconstitution of the Council and the Executive Committee. The Council will consist of elected members nominated by Groups according to the contribution to the general funds of the Federation made by each Group.

An important factor in self-government of Groups is their power to form sections within the Group for those of its members having common interests.

It is no doubt generally known that Government Departments prefer to deal with industrial matters through the respective trade associations. The power of Groups to form sections for members having common interests should, therefore, be of particular interest.

Concurrently with the reorganization, arrangements are being made to bring the Moulding Powder Export Group and the Moulders' Export Group within the ægis of the Federation.

In order to counteract exaggerated notices about plastics, the Council of the British Plastics Federation has set up a small sub-committee of the Publicity Committee for the purpose of offering their services to the Press on all matters relating to the publication of editorial publicity concerning the Plastics Industry. Inquiries should in the first place be sent to the General Manager, British Plastics Federation, 47-48, Piccadilly, W.1.

New Book

"Plastics—Scientific and Technological," by H. Ronald Fleck, M.Sc., F.I.C. Temple Press Ltd., London, 1943. Pp. 325, with 80 illustrations in line. Price 25s. net.

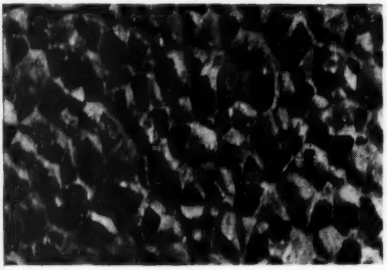
Mr. Fleck, whose knowledge of plastics is obviously vast, has produced a book which is up to date and all embracing. In it we see the steady growth of our industry which now covers such a broad canvas and in it we see the possibilities of a coherent, scientific and technical literature.

The author begins with a short history of plastics, followed by a chapter on raw material sources, paves the way for a detailed discussion of the chemistry of thermoplastic and thermosetting resins, which is logically followed by the technology of these two classes. The so-called synthetic rubbers (or elastomers) and the synthetic fibres are treated separately, although the general chemical aspects of these materials are included in the discussion mentioned above. An account is given of the physical properties, including electrical properties and water absorption, in which many modern tests, and theories advanced to explain the results, are critically examined. This field is completed by sections on synthetic resins; fibres and textiles; and adhesives, plywoods and impregnated woods. There are interesting chapters devoted to purely technical problems, which serve to orientate the reader's ideas on the commercial value of plastics.

One of the most striking features of the book is the inclusion of detailed instructions for the preparation (often on the technical as well as the laboratory scale) of both raw materials and finished products. This enables the prospective worker in this field to work directly from readily obtained chemicals, and the prospective manufacturer to appreciate the costs of the raw materials for any chosen plastic. Care has also been taken to present the most recent data available regarding the effects of fillers, solvents, water absorption, cure, etc., on the physical behaviour of various plastics.

The author's treatment of the colloidal properties of resins casts some light upon the generally unsatisfactory treatment of this subject in the majority of institutions of higher learning.

The index, however, is not well done, and no doubt will be corrected in subsequent editions. Illustrations are excellent, but a few good photographs would add to the value of the book.



EXPANDED PLASTICS

Recent Developments in this Field have Embraced the Use of Plastics other than Rubber. The accompanying Photograph shows the Non-intercommunicating Cellular Structure of these Special Types

IN June, 1937, we published a photograph of a remarkable door which was so light that a child could have lifted it, although it was the size and thickness of an ordinary door. It was faced with beautiful wood veneer, but its main composition was expanded ebonite made by subjecting rubber to nitrogen under pressure. This new cellular formation, in which the cells were non-intercommunicating, and thus different from spongy rubber, introduced a new type of structural material of exceptional lightness, strength and rigidity and extremely low thermal conductivity. It possessed, moreover, negligible water absorption, and was permanently buoyant. Onazote, as the material was termed, was the forerunner of a number of expanded materials that are to-day being produced by Expanded Rubber Company, Ltd.

During the past few years the need for producing expanded plastics in addition to rubber made itself evident, and to-day we have available structures made from thermosetting resins and most of the well-known thermoplastic compounds. Indeed, the properties can be varied to suit any particular need by choosing any specific plastic composition and density.

Thermazote (Expanded Phenolic Resin Type)

Obviously this has been introduced to meet requirements of heat resistance. It is manufactured in densities between 7 lb. and 30 lb. per cubic foot (S.G. about 0.12 to 0.5) and at its lowest density it has a compression strength of about 100 lb. per sq. in. (One cubic ft. of material of this density will support 55 lb. of soft iron in fresh water.) Its thermal conductivity is 0.28 British Thermal Units per sq. ft. per in. of material, and for 1 degree F. difference in temperature. Thermazote is non-inflammable, and is capable of withstanding temperatures as high as 250 degrees-300 degrees C.

Plastazote (Polyvinyl Formal Type)

The is an expanded thermoplastic material with an exceptionally high impact strength and modulus of elasticity under compression. At a density of 6 lb. per cubic ft. (0.096 S.G.) it has a compression strength of 170 lb. per sq. in. Its modulus of elasticity under compression is over 10,000 lb. per sq. in., and its thermal conductivity (at S.G. 0.096) is 0.24 B.T.U.

This material finds extensive application as a low density elastic stabilizing medium for sandwich construction, and can be readily shaped into curves.

Other Expanded Plastics

Several other plastics have been treated by the same process, and developments are being made with expanded polystyrene, casein, polyvinyl chloride, etc. A summary of the properties of these is given in the attached table.

Varied Applications

Buoyancy.—The extremely low density of the material, the non-intercommunicating-cell structure and the high water resistance of the basic plastics allow the

Summary of the Properties of Expanded Plastic Materials.

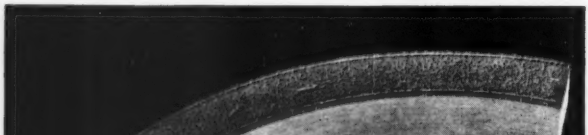
Properties	Thermazote (Expanded P.F. resin)	Plastazote (Expanded Polyvinyl formal)	Expanded Polystyrene	Expanded Polyvinyl chloride
Standard size	2 ft. × 1 ft. × 1 in. thick or mouldings	3 ft. × 2 ft. × ½ in. or ¾-in. thick	2 ft. × 1 ft. × 1 in. or more	½-in. or ¾-in. thick
Apparent density range	7–30 lb. per cu. ft.	6–30 lb. per cu. ft.	2–20 lb. per cu. ft.	10–20 lb. per cu. ft.
Lightest standard density	7 lb. per cu. ft.	6 lb. per cu. ft.	3 lb. per cu. ft.	12 lb. per cu. ft.
Thermal conductivity at above density	0.28 B.Th.U.	0.24 B.Th.U.	0.22 B.Th.U.	—
Maximum working temperature	250°–300°C.	70°–80°C.	80°C.	—
Inflammability	Does not burn	Burns slowly	Burns slowly	Varies according to plasticizer
Compression strength	100 lb. per sq. in.	170 lb. per sq. in.	50 lb. per sq. in.	—
Tensile strength	200 lb. per sq. in.	340 lb. per sq. in.	100 lb. per sq. in.	—
Impact strength	0.10 ft.-lb.	2.46 ft.-lb.	—	—
Impact strength with ⅛-ply veneer	1.34 ft.-lb.	3.70 ft.-lb.	—	—
Impact strength with 20g. dural	2.26 ft.-lb.	4.62 ft.-lb.	—	—
Modulus of elasticity under compression	4,000 lb. per sq. in.	10,000 lb. per sq. in.	—	—

introduction of buoys, floats, pontoons and general life-saving apparatus of high efficiency. Unlike cork, the phenolic, polyvinyl chloride, polyvinyl formal and polystyrene are unattacked by marine or other organisms.

Thermal Insulation.—As insulating material the expanded plastics find an obvious outlet in the refrigeration industry, including meat, fruit and ice cream vans and containers. This also applies to ship insulation and domestic refrigerators. In tropical climates there is an obvious field in special hospital construction and the like, and also for deck housings of boats and yachts employed in hot climates. Specialized applications in this field include the insulation of low-temperature scientific apparatus and plant.

Aircraft Construction.—Struts, wireless masts, tail-fairings, panellings for flooring and partition walls and instrument panels. Many other war-time applications cannot yet be disclosed.

General Construction. — Expanded plastics present interesting structures as elastic stabilizing media for building construction, as wall panels, floors, ceilings and doors with exceptionally high physical properties. As they can all be produced in reasonably large areas, they present a new series of structures for the prefabrication of houses. They can all be faced and backed with metal sheet.



Specimen of plywood/Plastazote sandwich in curved form.

The Future Possibilities of Ethyl Cellulose

By E. E. HALLS

The ether of cellulose, ethyl cellulose, had received but little attention in this country. Its value, however, is high and its versatility warrants the complete description given here.

CELLULOSE acetate has proved itself one of the most versatile of plastics; it has been extensively exploited in all its forms, has been readily available and has fully given the serviceability expected of it. It has been available in the form of sheet, film, rod, tube, and sleeving, all these in a range of colours, opaque and transparent. It has been readily procurable in powder form for moulding, again in a range of colours and transparencies, as well as in wood-filled varieties. Yarns, fabrics and tapes have likewise been obtainable. Also lacquers and cements have been marketed. All these have continued to be available in large quantities during the war period with, of course, the logical restrictions to priority applications. The electrical industry has been faithfully served by these products, and in this field some of them have been indispensable. Film, yarn, tape and lacquers fall in this category. Other fields, too, are strongly supplied. Films for packaging, sheets for display cards, films for photographic work, yarns and fabrics for clothing, curtaining, etc., transparent material for " windows."

Advantages and Disadvantages of Cellulose Acetate

It is stated that material has been available to satisfy these needs and to serve them faithfully. The properties of the products in question are well known and can be predetermined from chemical, physical and mechanical tests. Any shortcomings in the material, and as with all products there must be some, are known beforehand, and can be catered for.

One of the chief drawbacks to cellulose acetate is its response to some fluctuating conditions of atmospheric exposure, with special reference to changes in temperature and humidity. The results of such variations are particularly marked with sheet and film, tubing and sleeving. Electrical and " window " applications are most concerned. In such applications, care is taken to select the most suitable grades available in these respects so as to minimize troubles that result. At the same time, other plastics are examined and often exploited in particular instances to eliminate troublesome problems that would otherwise result. Many users have looked to ethyl cellulose and its commercial availability to replace cellulose acetate in many applications, but the position of affairs has always been disappointing in this country. Much information has been available on this plastic from the foreign Press, but the material has been virtually non-existent over here.

Characteristics of Ethyl Cellulose

At the same time, it has been very extensively exploited in both Germany and America. One valuable characteristic of ethyl cellulose is the fact that it retains its flexibility and resistance to impact at low temperatures, for example, down to — 40 degrees C., this in contrast to cellulose acetate, which embrittles. The manufacture of much Service equipment, and particularly of apparatus for aircraft, entails the use of materials that will withstand these low temperatures. Lack of productive capacity, and especially of production experience, for ethyl cellulose, must have been a handicap severely felt in our war industries. It is to be hoped that provision to fill these deficiencies will, in the post-war period, have provided us with the resources for this plastic in the future. Samples of ethyl cellulose manufactured in this country since the outbreak

of war have been exhibited, but bulk supplies are only available for restricted and important purposes. Of these samples, thin foil of the order of 0.001 in. to 0.002 in. in thickness, and sheet material in various colours and opacities, look exceedingly interesting. Such samples are not easily obtainable for experimental purposes, but a number of extended tests have been carried out from a small sample of ethyl cellulose sheet of thickness $\frac{1}{16}$ in. The tests, which were designed to cover stability, included the following:—

1. Complete immersion in water at ordinary temperatures.

2. Exposure to dry heat at 60 degrees C.

3. Exposure to fluctuating conditions of warmth and dampness. These conditions comprised cycles as follow:—

Day temperature 55 to 60 degrees C. with a humidity of 65 to 75 per cent. Temperature at night cooling down to atmospheric with rise in humidity to 100 per cent. and moisture condensation upon all specimens.

The behaviour of the specimens under test was followed by taking dimensional and weight measurements at intervals of time. The results are summarized in Tables 1-3. Also in Tables 4-6 are given similar data with respect to typical samples of $\frac{1}{16}$-in. thick celluose acetate

Table 1.—Effect of Water Immersion at Laboratory Temperatures, upon $\frac{1}{16}$-in. thick Ethyl Cellulose Sheet—Changes per cent. in Dimensions and Weight.

Period of water immersion in days	Total increase per cent. in:—			
	Weight	Length	Width	Thickness
1	2.4	0.6	0.6	0.8
14	3.8	1.4	0.9	1.3
30	4.0	1.6	0.9	1.3
90	4.4	1.0	0.9	1.3
180	4.6	1.0	1.4	1.6

Table 2.—Effect of Dry Heat at 60°C. upon $\frac{1}{16}$-in. thick Ethyl Cellulose Sheet—Changes per cent. in Dimensions and Weight.

Period at 60°C. in days.	Total change per cent. in:—			
	Weight decrease	Length decrease	Width decrease	Thickness increase
1	1.0	Nil	Nil	0.2
14	1.8	0.4	Nil	1.6
30	2.0	0.4	Nil	0.5
90	2.1	0.6	1.5	0.5
180	2.3	0.9	2.0	0.5

Table 3.—Effect of Fluctuating Conditions of Heat and Humidity upon $\frac{1}{16}$-in. thick Ethyl Cellulose Sheet—Changes per cent. in Dimensions and Weight.

Period of test in days.	Total change per cent. in:—			
	Weight	Length decrease	Width	Thickness increase
1	Increase 1.6	Nil	Nil	0.5
14	Increase 0.8	Nil	Nil	1.2
30	Increase 1.4	Nil	Nil	1.5
90	Decrease 0.45	0.6	Nil	0.8
180	Decrease 0.45	0.6	Nil	0.8

Table 4.—Effect of Water Immersion at Laboratory Temperatures upon $\frac{1}{16}$-in. thick Cellulose Acetate Sheet—Changes per cent. in Dimensions and Weight.

Period of water immersion in days	Total increase per cent. in:—			
	Weight	Length	Width	Thickness
1	2.3	0.7	1.0	1.0
14	4.8	0.9	1.6	1.7
30	7.0	1.0	1.9	2.2
90	10.0	1.4	2.3	2.7
180	12.0	2.0	2.7	3.5

Table 5.—Effect of Dry Heat at 60°C. upon $\frac{1}{16}$-in. thick Cellulose Acetate Sheet—Changes per cent. in Dimensions and Weight.

Period at 60°C. in days.	Total change per cent. in:—			
	Weight decrease	Length decrease	Width decrease	Thickness decrease
1	2.3	0.9	0.6	1.2
14	4.9	1.6	1.1	1.8
30	6.1	2.0	1.3	2.2
90	7.5	2.5	2.2	2.8
180	8.3	3.0	2.6	3.0

Table 6.—Effect of Fluctuating Conditions of Heat and Humidity upon $\frac{1}{16}$-in. thick Cellulose Acetate Sheet—Changes per cent. in Dimensions and Weight.

Period of test in days	Total change per cent. in:—			
	Weight increase	Length decrease	Width increase	Thickness increase
1	0.3	0.5	0.5	0.8
14	1.8	0.7	0.8	1.4
30	2.0	0.9	0.9	1.7
90	2.2	1.1	1.0	1.9
180	2.5	1.3	1.2	2.1

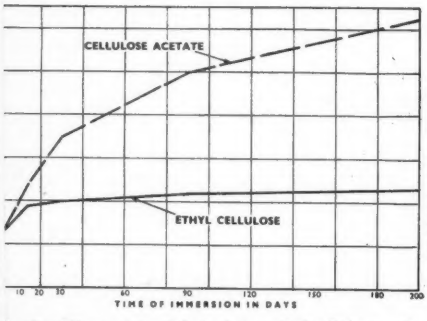
Table 7.—Comparative Softening Points of $\frac{1}{16}$-in. thick Ethyl Cellulose Sheet and Cellulose Acetate Sheet.

Ethyl Cellulose	110°C.
Cellulose Acetate	120°C.

heet. A comparison of the performance f the two materials can be made from he test results as follows:—

Under the continuous water immersion thyl cellulose showed an increase in veight and in all dimensions. This ncrease tended to reach a maximum in 4-30 days and then remained fairly con-tant. The cellulose acetate, however, howed a rather more gradual increase in ach respect and the weight increase was very much higher. The dimensional increases were at least twice those of the ethyl cellulose.

In the case of the dry heat test the ethyl cellulose showed a decrease in weight and a shrinkage in length and width with a small swelling in thickness. The cellulose acetate showed a decrease in each respect. Again the change with cellulose acetate was very much higher than with ethyl cellulose. The weight



ig. 1.—Change in weight in $\frac{1}{10}$-in. ethyl cellulose and cellulose acetate sheets upon water immersion.

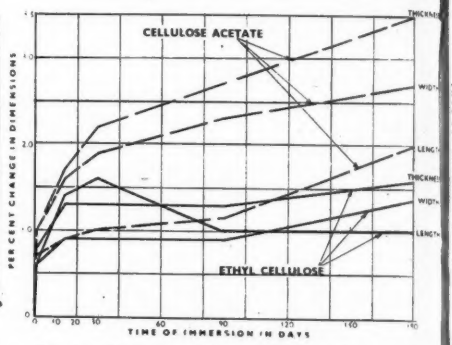


Fig. 2.—Change in dimensions of the same sheets upon water immersion.

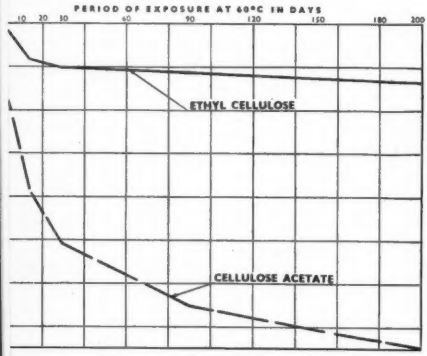


Fig. 3.—Loss in weight of the sheets upon exposure to dry heat at 60° C.

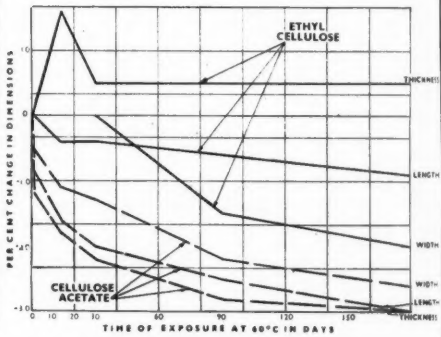


Fig. 4.—Change in dimensions of the sheets upon exposure to dry heat at 60° C.

loss was four and the dimensional loss three times those of ethyl cellulose.

Under the fluctuating conditions of warmth and moisture very small changes occurred with ethyl cellulose, some being increases and some being decreases. With cellulose acetate the percentage change was again much more marked.

From these results it is concluded that ethyl cellulose has advantages over cellulose acetate in being dimensionally appreciably more stable than cellulose acetate when exposed to conditions of warmth or of wetness, or to a combination of these conditions.

The course of the tests with respect to changes in weight and dimension can best be followed from graphical representation. The data from Tables 1 to 6 are accordingly plotted in Figs. 1 to 6. Figs. 1 and 2 show weight and dimensional changes respectively under water immersion conditions, Nos. 3 and 4 similarly represent the dry heat test results, and Nos. 5 and 6 show the influence of the cyclic humidity test. They are drawn in a manner to show clearly the relative behaviours of the ethyl cellulose and cellulose acetate respectively and bear out the superiority of the former.

Finally, with regard to response to temperature, comparative softening points of the two materials are given in Table 7. These were assessed by extension methods under dry heat, and it will be seen that the ethyl cellulose will, if anything, with-

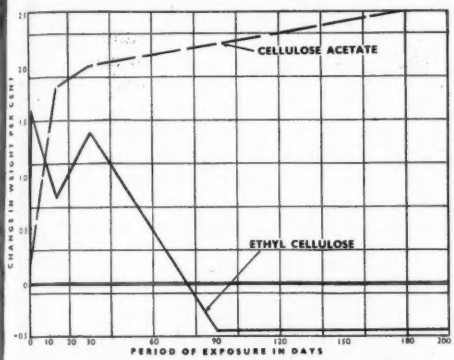


Fig. 5.—Change in weight of $\frac{1}{16}$-in. ethyl cellulose and acetate sheet upon exposure to cyclic heat and humidity.

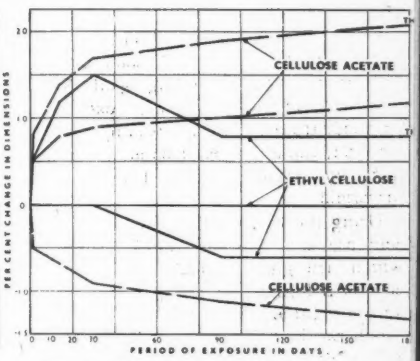


Fig. 6.—Change in dimensions of the same sheets upon exposure to cyclic heat and humidity.

stand a slightly higher temperature than cellulose acetate.

Before making any final judgment on the material, naturally a more extensive range of samples should be studied. Such features as plasticizing as well as form and dimensions may have some bearing on performance, but the broad indications are that ethyl cellulose could advantageously replace cellulose acetate in many instances. Ethyl cellulose plastics are, in fact, considered to be of sufficient importance for the future to review herein their general properties and established and suggested uses.

Several firms in this country are now interested in the manufacture or supply of ethyl cellulose. Messrs. B.X. Plastics, Ltd., produce the material. In sheet form they offer it in size 54 ins. by 24 ins., with thicknesses from 0.005 in. upwards; extruded rods and tubes are also produced, and in all these materials the usual range of colours can be obtained. The average properties of B.X. ethyl cellulose are given in Table 8, which shows it to be a sound material both mechanically and electrically. Its resistance to weak acids and to alkalis should be noted. Water absorption is low, and stability under hot conditions, damp exposure or when subjected to atmospheric influences has already been established as relatively very good.

Ethyl cellulose is stable under the influence of light and resistant to ageing, superior to the acetate and much superior to nitro cellulose in these respects. It allows free passage of light rays, including the ultra-violet wavelengths. Stability to alkalis means that usual soaps and detergents can be used for "cleaning" windows.

Chemical Composition of Ethyl Cellulose

Contrasting with nitro cellulose and cellulose acetate, ethyl cellulose is an ether and not an ester. In its production, the starting point is, of course, cellulose, such as wood pulp or cotton linters. The cellulose is treated with a strong aqueous solution of caustic soda to form alkali cellulose. This is then alkyated with ethyl chloride or sulphate. Operating control

Table 8.—Properties of Ethyl Cellulose.

Specific gravity	1.20
Tensile strength	4,000-8,000 lb. per sq. in.
Modulus of elasticity	2.0 to 4.0 × 10^5
Impact strength (Izod)	0.6 to 1.5
Brinell hardness	5 to 10
Water absorption (48 hours)	1.25%
Softening range	70 to 90°C.
Breakdown voltage	1,500 v. per mil.
Dielectric constant (60 to 1,000 cycles)	2.5 to 3.7
Power factor (10^3 cycles)	.01 to .03
Burning rate	Slow
Effect of weak or strong alkalis or weak acids	Slight
Soluble in ketones and esters. Softens in alcohol.	

is necessary for the prevention of undesirable degradation of the cellulose and destruction of the ethylating agent. When etherification is complete, excess of reagents are removed by washing and distillation; the ethyl cellulose is easily purified by washing free from soluble materials.

Using the long-chain conception of the cellulose molecule, the building units of which are glucose residues having the empirical formula $C_6H_{10}O_5$, each of these units has three available hydroxyl groups, which can be substituted. Ethyl cellulose is the ether in which the hydrogens of these hydroxyl groups are replaced by ethyl groups. In the average commercially available product, this substitution has been achieved to the extent of 2.4 to 2.5 of the three hydroxyl groups in the glucose residue. This corresponds to 47 to 48 per cent. ethoxyl content, and this particular form of ethyl cellulose has the widest range of useful properties. Thermoplasticity coupled with unusual toughness and low inflammability are its characteristics. The unplasticized material is flexible at temperatures as low as -40 degrees C. and is very extensible. These properties give to ethyl cellulose at low temperatures a degree of toughness unequalled by other plastics. Its burnability is akin to that of cellulose acetate and it yields harmless gaseous products of combustion. Its stability to heat makes it quite suitable for the normal thermoplastic processes such as extrusion and moulding. Its chemical resistance gives it applications in chemical engineering, and its low water absorption (this lying between those of cellulose acetate and nitro cellulose) coupled with its dielectric properties, renders it a useful electrical material. Compatibility with many oils, waxes, resins and plasticizers and solvents in general, create possibilities of modified products as well as of adhesives and cements, paints, lacquers, varnishes and electrical coil dopes.

Ethyl cellulose does not suffer from any drawbacks from density, its specific gravity comparing very favourably with those of the other cellulose plastics. For ethyl cellulose the value falls within the range 1.14 to 1.20, for cellulose acetate 1.35 to 1.40 and for nitro cellulose about 1.65 to 1.70.

Behaviour to Solvents, Etc.

The straight-chain petroleum hydrocarbons comprise one group of organic solvents having no marked solvent action for ethyl cellulose. Good solvent combinations, used in America, are mixtures of aromatic hydrocarbons and aliphatic alcohols. For example, one such blend comprises 70 to 80 parts by weight of toluene, or a hydrogenated naphtha such as Solvesso, with 30 to 20 parts of industrial methylated spirit.

Plasticizers are almost unlimited, and include high-boiling-point esters, raw oils, blown oils, fatty acids and the chlorinated diphenyl derivatives. Heat-bodied oils can only be used in small quantities, or in the presence of a third mutually compatible ingredient, as they themselves are relatively immiscible. Wax-like materials may include all the animal or vegetable ester-type waxes, the earth waxes such as the montans, and the pitches of coal tar and fatty origins. Paraffin wax is immiscible unless a mutually compatible third ingredient is present, when it can be incorporated in appreciable quantities.

Many natural resins, including all the alcohol-soluble varieties, are compatible; of the synthetics, the phenolics, rosin-modified phenolics, rosin-modified maleates, long-oil and fatty-acid-modified alkyds, and many miscellaneous resins such as the ester gums are compatible. Limited compatibility is exhibited by some hydrocarbon, urea-formaldehyde, short-oil-modified alkyds and oil-modified phenolic resins, rendering them quite useful when only low percentage additions to the ethyl cellulose are demanded. Again, there is always the possibility of incorporating larger amounts by using the third mutually compatible ingredient.

Ethyl cellulose dissolves quite readily in hot resins, oils, waxes and plasticizers, and in mixtures of these, without the aid of solvent. Thermoplastic mixtures result, which find use as cements, adhesives or

coatings, especially for luting, sealing, jointing, chemical resistance, electrical insulation and associated applications.

American manufacturers have classified ethyl cellulose into a range of grades based on ethoxyl content, but within each grade is a wide range of viscosities, viz. :—

Grade.	Ethoxyl Content %.
T	48.5—50.0
N	46.8—48.5
K	45.5—46.8
G	44.5—45.5
D	43.5—44.5

The plastic powders can be produced with or without the aid of solvents. Using solvent, orthodox processes of mixing, sheeting, drying and granulation are used. Without solvent, compounding is achieved in a Banbury mixer or by the heated two-roll process. As there are no solvents to expel by the non-solvent method, seasoning or maturing is avoided; the method is quite successful for heavily pigmented types, but with delicate tints the possibility of some darkening by heat must not be overlooked.

Less plasticizer is required for ethyl cellulose than for cellulose acetate to give the same flexibility. High-strength thin foils and sheet can be produced without plasticizer, and these still have sufficient flexibility for many purposes. This is a very important feature because it is often loss of plasticizer gradually during service that accounts for much instability. Packaging, "window" applications and electrical uses can advantageously utilize such materials.

Manifold Applications

Extruded strips in attractive colours have been used instead of flexible cane or reeds for domestic furniture.

Carefully plasticized material is also extruded over electrical conductors to give insulating coverings. Controlled temperature in this process ensures proper adhesion and permanence of adhesion, and the toughness of the extruded layer is such that the covered wires, when crossing one another in assembled equipment, do not cut through one another and short circuit. Superiority in this respect is expected over the results achieved with polyvinyl chloride coverings.

The ready response to fabrication processes has caused ethyl cellulose to be used for packagings. Transparent rigid "boxes" are made from foil and sheet in thicknesses from 0.003 in. to 0.020 in. "Deep drawing" is readily achieved for round and square, hexagonal and other irregular sections. The material is used warm for these upsetting operations, but well below 300 degrees F. in order not to diminish the initial lustre, colour, or strength of the sheet material, and many drawing operations can apparently be achieved successfully without warming the material.

These containers for packaging are rigid yet flexible, they are tough and strong, relatively stable with respect to dimensions, and of low moisture absorption.

The injection moulding field can also look to a good future with ethyl cellulose. Technique is closely the same as that for cellulose acetate, and a full range of colours, opaque or transparent, is possible. The moulded articles possess the characteristic properties of the base ethyl cellulose, with toughness over a wide temperature range, water resistance and dimensional accuracy outstanding. Excellent dimensional stability can be assured because far less volatile plasticizer is employed than is necessary for cellulose acetate, and, again, for some purposes non-volatile resins can be employed. The usual inorganic fillers can be employed, and zinc oxide is one of the most popular. Up to 30 per cent. by weight may be employed before any decrease in toughness becomes apparent.

Typical proportions of plasticizers are 10 to 20 per cent. for compression moulding, 15 to 30 per cent. for injection moulding materials, and up to 50 per cent. for extra flexible extrusion products. The following examples of nominal compositions give some guide as to the formulations employed. The plasticizers named can, of course, be substituted by others. Percentages are by weight.

Table 9.

Opaque Compression Moulding	
Plasticizers—triphenyl phosphate	7.5%
dibutyl phthalate	7.5%
Filler—zinc oxide	22.5%
Pigment—colour	To suit
Stearic acid	1.5%
Ethyl cellulose	61%
Transparent Injection Moulding	
Plasticizers—diethyl phthalate	6%
triphenyl phosphate	3%
camphor	7.5%
Stearic acid	2%
Ethyl cellulose	81.5%
Opaque Injection Moulding	
Plasticizer—methyl phthallyl ethyl glycollate	20%
Filler—zinc oxide	22%
Colour	To suit
Stearic acid	1.5%
Ethyl cellulose	56.5%
Flexible Extrusion Material	
(1) Plasticizer—petroleum jelly and dibutyl phthalate	20% to 50%
ethyl cellulose	80% to 50%
(2) Plasticizer—hercolyn	50%
Ethyl cellulose	50%

Stearic acid assists in avoiding sticking in moulds. (See Table 9.)

It is interesting to note that ethyl cellulose is compatible with nitro cellulose, the one conferring its mechanical properties on the other to some extent. Fifty-fifty mixtures in film form have a hardness about equal to that of nitro cellulose, with 50 per cent. of the flexibility of ethyl cellulose. With 80 per cent. ethyl cellulose, flexibility of the latter is said to be undiminished, but hardness is improved. Further, with these films, the burning rate of nitro cellulose is subdued and reduced to about the same level as that of ethyl cellulose itself.

From the paint, varnish, enamel and lacquer angle a wide field of possibilities exists. Ethyl cellulose dopes are suitable for paper coatings to impart moisture resistance, flexibility and toughness. Incorporation of a percentage in varnishes gives reduced drying times, decreases surface tackiness, and improves toughness and flexibility of the film. It may be incorporated in the oil or added to the finished varnish as a solvent solution. It can also be used to improve the dispersion of pigments. For this purpose the ethyl cellulose and pigment are compounded in a Banbury mixer, whereby the pigment is easily "wetted" by the plastic. The mixture then disperses easily in the paint medium in a suitable solvent suspension, improved covering capacity or obliterating power results. Again, ethyl cellulose has similar uses to chlorinated rubber for "wet-on-wet" systems, that is, systems in which primer, surfacer and finishing coat are successively applied and given one drying-off or stoving period.

Naturally, the foregoing has been far from complete in its survey, but sufficient has been said to demonstrate the unique properties of ethyl cellulose and some of the directions in which they have been exploited. For the reasons amply illustrated, it is hoped, and expected, that the material will be more extensively exploited in this country in the post-war period.

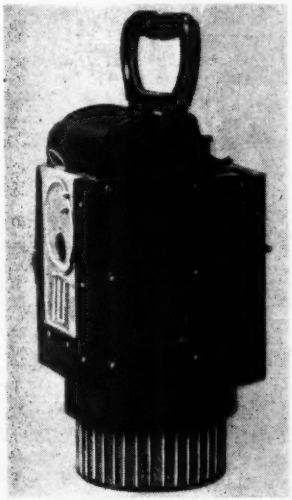
Captured German Plastic Lantern

THE following is a description of a German field service lantern captured from the enemy. It is largely made of plastics.

The lantern is lit by acetylene, which is produced by the action of calcium carbide and water. The gas is generated in a circular container at the base of the lantern and burns in the main body, which is approximately cubical in shape. The water is stored in the tank at the rear and the flow to the calcium carbide is regulated by the usual screw adjustment. The top of the lantern is domed, and a handle is hinged to this.

The lantern can be considered to consist of three main parts. These are the body, which houses the burner; the generator; and the water tank and burner assembly.

The body is approximately 5 ins. high, 4 ins. wide and 3 ins. deep, and the sides, back and bottom are moulded in one piece. The front is hinged along one side and contains a glass window with metal shutters held in a moulded plastic frame. The shutters are fitted with sliding screens so that either no light may escape or a circular or slit beam may be produced. When shut, the door is held in place by a metal clip which is secured by a knurled finger nut with a brass-threaded insert. Both sides of the body have glass windows. Moulded plastic frames riveted on to both sides allow the shutters to be inserted, if desired, to prevent light showing. These frames are designed to permit ingress of air to the combustion chamber. Inside at the back a reflector is fixed. The bottom contains a hole through which the burner protrudes. The top of the body is made of metal to resist the heat, and is riveted on to the plastic sides and back.



The dome is a separate moulding which fits over and is riveted to the metal top of the body. When viewed from the side it appears as a semi-circular tube $1\frac{1}{2}$ ins. high and $\frac{1}{4}$ in. thick. A plastic handle is fitted to the dome by two bored projections about $\frac{1}{2}$ in. diameter and $\frac{1}{2}$ in. wide, which fit into corresponding holes in the dome; a metal rod running through the projections and the dome acts as a hinge.

The water tank is made of metal, and has dimensions $\frac{3}{4}$ in. side, $3\frac{1}{2}$ in. width and 4 ins. height. This fits into a plastic frame, the top of which is open. At the bottom of the frame is a horizontal projection. The body of the lantern slides into place on top of this projection by means of two slots which coincide with two vertical ridges on the tank frame. It is secured in place by a spring clip. Rising vertically from the centre of the projection is a spigot $1\frac{1}{2}$ ins. high and $\frac{5}{8}$ in. in diameter. The frame, projection and spigot consist of one moulding. There is a $\frac{3}{8}$-in. air gap between the frame and the back of the tank. The purpose of

(Continued on p. 96)

World's Industry Employs Plastics

GENERAL ENGINEERING

Synthetic resin cement of novel properties, developed in Canada and produced by the U.S. Stoneware Co., is said to give rubber-to-metal bonds with strength of adhesion up to 1,200 lb./sq. in. in tension, the precise figure depending on the type of rubber and the nature of the metal to which it is bonded. It is to be observed that no brass plating is required. Some synthetics, such as neoprene and thiokol, normally reckoned difficult to bond to metal, gave excellent joints. With the same adhesive metal-to-metal bonds have been developed, giving a sheer strength up to 3,000 lb./sq. in. Metal-bonded plywood develops bend strengths superior to the strength of the wood itself. Some types of thermosetting plastics may be effectively bonded to metal. **Translucent skin of ethyl cellulose plastic** has recently been developed by the Dow Chemical Co. It is employed for protecting machine parts in shipment and shows definite indications of facilitating the flow of new and replacement parts to the battle fronts. It is applied by dipping, and besides affording perfect protection to delicate parts, cuts packaging time by as much as 80 per cent. So effective is the material in protecting metal from dirt and salt water that parts may be tossed overboard by high tide near invasion points to be recovered later by repair crews when tide and fortunes of war permit. **Phenolic resin boards** produced on standard paper-making machinery can be successfully utilized for parts requiring high impact strength. Other advantages are high moisture resistance and notable dimensional stability. In " Product Engineering," 1943/14/638, Nash and Vaill describe the correct moulding technique. The production of plastic bayonets in this material for parade and drill purposes has released vast quantities of steel bayonets for overseas use. In the same journal for October, 1943, are given details of **spray nozzles accurately machined from extruded bar stock in polystyrene,** which was selected because of its high acid resistance and because of the close machining tolerances which it permitted. **Strength testing of components** by means of brittle lacquers is now extensively applied for stress investigations of the actual parts. A suitable natural resin dissolved in carbon disulphide can be employed for the purpose, and by the addition of plasticizers during the manufacture of the lacquer the strain at rupture under different conditions of temperature and humidity can be controlled (" Product Engineering," 1943/14/611).

CHEMICAL

Very light industrial thermometer has been developed by C. J. Tagliabue Co., Park and Nostrand Avenue, Brooklyn. The design has been made possible by generous use of plastic. The rectangular case, for example, is not affected by surface temperatures, whilst the plastic yellow background contrasts well with the mercury column and give opportunity for fitting a readily interchangeable glass cover. Not the least advantage of the use of plastics in this connection lies in the added robustness and resistance to mechanical and thermal shock achieved.

AIRCRAFT

Forming of plastic sheets into cylindrical shapes and compound curves at low initial cost is described by Th. Moss, 33, Flatbush Avenue, Brooklyn. An aeroplane panel 27 ins. by 7¾ ins. can be accurately moulded to accommodate levers and knobs, and provided with depressed white letters on a black panel.

FANCY GOODS

Substitute cork, manufactured by aerated plastic, was referred to in a recent broadcast from Germany. Certain uses were specified; for example, for foot arch supports, pen and pencil holders and walking-stick handles. The artificial limb industry is also making use of this material, whilst a company has apparently been formed for the manufacture of tool handles of the same material.

MISCELLANEOUS

Thermosetting resins requiring no external pressure during the moulding process have recently been developed and were described by Armstrong in a paper entitled "No-pressure Laminated Plastics," read before the American Society of Mechanical Engineers. The paper is abstracted in "Machine Design," 1943/15/133. When used in combination with high-strength fillers, laminated plastics of high strength and low density are produced. For instance, one or more layers of a suitable base are wrapped round the moulding, saturated with liquid resin and cured by application of heat, not exceeding, as a rule, 240 degrees F., with corresponding curing time of 30 minutes to 8 hours. The technique clearly eliminates, for certain purposes, the need for expensive moulds, but is not entirely novel, as in past issues of "Plastics" detailed reference has been made to plastic bearings of the wound type, produced by a precisely similar technique. **Classification of plastic materials** on the basis of engineering properties rather than chemical nature, is an objective of the Technical Committee of the Plastic Industry (U.S.A.). It is felt that when the new classification is made available design engineers will be greatly assisted in the specification of plastics. The work referred to is to be the beginning of a handbook of authoritative information on design criteria and recommended practices for the moulding and fabricating of all plastic materials ("Machine Design," 1943/15/110). **Use of cellulose plastics** was made the subject of check by the U.S.A. War Production Board. It was shown that 14 moulders with a capacity of 1,500,000 lb. per month placed orders in excess of £4,000,000 for October. These excessive orders were deemed illegal and were refused. Equitable distribution, it is felt, should give sufficient material for this to be available for approved civilian uses. **Cellulose fibre** manufactured from eucalyptus is receiving the attention of the Spanish Government, represented by the National Industrial Institute, in collaboration with an Italian company. According to a Dutch broadcast, the new factory, which will start production in the coming spring, appears to have obtained a licence from the German Phrix Co. **Recently developed materials** are classified alphabetically by trade names in "Machinery" (New York), for October, 1943, to November, 1943. Plastics and rubber substitutes figure largely in the list. **Designing of plastic parts** formed the subject of paper by Larson, abstracted in "Machine Design," 1943/15/192.

Coal in Relation to Plastics

By H. RONALD FLECK, M.Sc., F.I.C.

A broad canvas on which is drawn the vast array of plastics and chemicals that are being or can be made from coal, which must be our main raw material for many years to come.

COAL—"black diamonds," the brightest jewel in the diadem of this island—is probably the greatest single source of wealth that this country possesses. The output of coal from the British coalfields is in the region of 220,000,000 tons annually and it forms the keystone of practically every industry in the form of heat, as electric power and gas, or as raw material.

No other single natural substance can yield so vast an array of materials as coal can. The by-products of coal carbonization form the starting point for complicated organic syntheses giving rise to thousands of intermediates and final products. Dyestuffs, medicaments, fuels, explosives, perfumes, flavouring matters, photographic developers and plastics are all derivable from coal. The skill of the scientist has unlocked this treasure chest of Nature and but a few of the treasures it contains have yet been examined. The scientist, in common with all Mankind, requires adequate remuneration in order that he may eat and live. Research work is expensive and without research we cannot possibly gain all that we should know about coal and its by-products.

Individual or State Research

The question arises: "Is research to be a charge on an individual or is it properly a charge on the State?" This question is an important but controversial issue. Let us examine it and try to get our facts in their proper perspective without, if possible, going into deep political arguments. The mining industry, the basic factor of the whole edifice, employs many thousands of workers whose affairs are very properly watched by the State. We have had experience in comparatively recent years of the chaos and utter confusion into which the whole country can be thrown by the cessation of labour on the part of the miners, whether for real or imaginary grievances is beside the point. Admittedly, mining is an arduous and dangerous job calling for skill and tenacity on the part of the miners, and it is right that such work should be paid for on a scale commensurate with its discomforts and dangers. The owners of the mines retort, however, that the price they receive for the coal is insufficient to enable them to pay the operatives more wages than they do already and the average consumer naturally is not disposed to pay more than he has to for the coal. The salient fact now emerges: "Can we make our coal more valuable by getting more out of it?" Coal is wasted to a vast extent throughout the world simply by burning it. By this process heat is liberated, true, but the valuable by-products are all lost. Moreover, much money is spent in towns and cities in making good the ravages of coal smoke. In Chicago alone some $40,000,000 are spent annually in repairs directly attributable to coal-smoke damage. Properly organized research can indicate how to abate this nuisance and at the same time recover the by-products. Every industry will benefit and so will every individual.

Who then is to foot the bill? Two proposals come to mind (a) a levy on all industries concerned or (b) Government-sponsored research. If we levy all industries how are we to apportion the amounts due? The amounts must be equitably proportional to the benefits which each industry may expect from such a co-operative effort. The difficulty is that some industries will benefit only very indirectly but they may benefit enormously. Until the research points the way we cannot

know how far an industry will benefit, and even the wisdom of Solomon would be taxed to its limits to decide beforehand how much such a hypothetical industry was to contribute to the pool. Again, many millions of individuals must of necessity gain from such a project and yet would not be financially responsible for the work. These facts alone would appear to render such a co-operative effort untenable owing to the immense ramifications of the coal industry and its satellite industries.

Technical Eminence by Research

What then of our alternative proposal —Government-sponsored research? This, I think, is the answer to the problem. The Government is in a position to spread the cost over every individual by including a provision for coal research as a tax in the Budget. Such a provision must, however, be made with a generous hand. A start has been made, admittedly a tiny start, by the grant of £1,000,000 spread over five years for the fostering of research into the utilization of coal. This is not nearly enough. It will provide only sufficient funds for a team, say 40 strong, for remember that the plant for such research will be expensive and is apt to grow like a rolling snowball. Think of the benefit to be gained; coal research properly organized and adequately endowed can achieve the touch of Midas and amply repay the money and the foresight of the Government with courage enough to grant £10,000,000 per annum for a long-term fundamental research covering, say, 10 years. Consider that all aspects of coal production, utilization and scientific exploitation in the chemical and physical senses must be examined thoroughly and from first principles and I think it will be agreed that the sum mentioned is not excessive.

It is the purpose of this article to attempt to delineate the method by which success can be achieved in coal research in relation to the young and lusty plastics industry. Let us examine our industry from the point of view of its post-war possibilities.

Politically the Briton is too prone to hide his light under a bushel, but one fact stands out starkly. For peace to come to this troubled world to stay, the British Commonwealth of Nations and the Colonies must endure as they endured alone in 1940 to save civilization. It is no time to cavil at immodesty, we must urgently ensure that we retain our pre-eminence in the councils of the world. Such a dominant political position is vouchsafed only to those nations whose industries are pre-eminent. Any post-war planning must of necessity take this factor into consideration. Only by upholding our export trade can we uphold our benevolent political influence, and we have mortgaged our export trade pretty heavily in our effort to withstand the barbarism which at one time threatened to engulf the world. How can we regain our position? The problem is complex, too complex for me to attempt to solve, but surely the sale of first-class products at competitive prices built up our trade once and must do so again. Each industry must play its part in this equally vital peace-time battle for existence. The infant plastics industry must bear its banner with the rest and must exhibit that superlative workmanship which indelibly stamps British on any article made in this tradition. How are we placed to play our part?

The Necessity for a Carbide Industry

A vast array of plastics are derivable from coal, as the chart in Fig. 1 shows. But one factor is of very grave importance, it is this: we have no carbide industry; yet calcium carbide is an essential raw material in the production of many plastics. This state of affairs demands immediate attention and rectification, but a flourishing carbide industry can be built up only with the aid of cheap electricity. In those countries possessing many fast-flowing streams and waterfalls huge hydro-electric schemes can be set up which will yield abundant supplies of electric current for very little expenditure. Such hydro-electric schemes are feasible in Scotland, as the success of the Fort

William Installation has shown. They must be extended for the benefit of other industries. Given cheap electricity we have all the lime and coke we need for this vital raw material—calcium carbide. From the chart we can see the range of plastics derivable from carbide through calcium cyanamide and acetylene—melamine resins and plastics, acrylate polymers, Buna and Neoprene synthetic elastomers of rubbery consistency, methacrylate resins, acetic anhydride and acid for the production of cellulose esters, synthetic drying oils for the paint industry, polyvinyl alcohol, acetate and aldols. A noble array, and one which can be further extended if we postulate a serviceable method of polymerizing acetylene to benzene, a synthesis which has been achieved academically. All these derivatives can be credited to coal via the coke used in the production of the carbide. This is an economical use for coal since 10 tons of coal will on carbonization give 7 tons of coke yielding in its turn about 12 tons of calcium carbide. This amount of carbide will give us 5 tons of acetylene or 2 tons of melamine. On the other hand 10 tons of coal will yield only about 35 lb. of mixed phenols and cresols, 13 lb. of coumarone and indene, 5-6 lb. each of benzene and toluene, and 60 lb. of naphthalene, a total of 120 lb. of plastic-forming material. In the U.S.A. in 1938 some 100,000 tons of phenol plastics were produced representing the expenditure of some 60,000,000 tons of coal, whereas there could have been produced some 12,000,000 tons of melamine plastics from the same amount of coal. Obviously, of course, melamine cannot replace phenol entirely, but some happy compromise must be found. Carbide forms the answer; we can have our 12,000,000 tons of melamine and our 100,000 tons of phenol plastics provided we convert the coke obtained during the phenol production into calcium carbide.

Sub-surface Combustion

A further line of research which will probably prove very profitable is being pursued in Soviet Russia and should be watched with considerable interest by all interested parties in this country. Briefly, the scheme is to turn a coal-mine into a gigantic gas-retort by firing the coal seam itself. This, of course, will avoid the expense of mining the coal and although if it is successful and achieves widespread popularity it will cause a diminution in the number of miners required, this fact in itself will not militate against its adoption. Coal mining is an arduous and dangerous job and increasing numbers of men are showing very plainly their dislike of such labours. Voluntary service in the coal mines has proved very unpopular in this war and it has been necessary to resort to conscription cloaked by a ballot, appealing to the sporting instinct of youths in order to get the minimum amount of labour required. This antipathy may mean that we become short of miners just as our expanding industries need more and more coal. The Russian scheme, if sponsored as a State field of research, may lead to profitable results in spite of lack of hewing labour. Much of the displaced man-power would in any case be absorbable in the necessary chemical plant at the head of the burning seam.

The Method of "Gassing"

The method of "gassing" a seam is to drive two shafts down into a coal seam in such a manner that the seam forms a lateral gallery joining the two shafts. To one shaft is attached the necessary condensers, stills and gas holders, i.e., a complete gas-works installation; to the other shaft is fitted a powerful fan to drive the evolved gases along to the farther shaft. The coal seam is then ignited and the products of combustion are blown along the seam, up the shaft and the normal gas-works procedure of separating tar, gas and ammoniacal liquor is carried out in the over-ground installation. When gas is no longer evolved the seam consists of a layer of white-hot coke. Steam is now blown down into the seam and the water-gas thus produced—a mixture of carbon monoxide and hydrogen—is by-passed at the head of the second shaft into gas-

holders. Reference to Fig. 1 will show the plastics derivable from water-gas through formaldehyde, methanol (or methyl alcohol) and formamide. Water-gas has a very high calorific value and could be piped off to outside consumers or it could be utilized for providing the heat necessary to run the plant, installation and blower.

Water-gas can be compressed to a liquid from which pure hydrogen and carbon monoxide are obtainable by fractional evaporation. Pure hydrogen finds many uses in industry and would form a valuable by-product. Carbon monoxide will unite directly with chlorine to give liquid carbonyl chloride (phosgene) which in turn unites with ammonia (also produced at the shaft head from ammoniacal liquor) to give urea with ammonium chloride as a by-product. Thus by coal-seam carbonizing we get phenol, benzene, toluene, urea, formaldehyde, methonal, and formamide ready for conversion into plastics, and all these are produced on the site of the coal and without mining it. This is a fine field for research on the part of the coal industry as a whole, and it is to be hoped that it will receive the attention it deserves.

The Synthetic Rubber Situation

What of rubber and those synthetic materials—plastics all of them—which go by the generic name of synthetic rubbers? How will this war affect them? The United States of America have set up an enormous industry for producing these synthetic plastics to replace natural rubber as far as possible during the time of hostilities. We, perhaps somewhat unfortunately, have agreed that the U.S.A. shall produce the greater part of the requirements of the United Nations in this respect. The exigencies of the present conflict have no doubt made this course necessary, but the warning tocsin must be sounded; we have had experience of the basket containing the eggs being upset—in France. In peace, however, competition will return, in fact must return as a basis for sound trading, and war-time Allies will find themselves peace-time competitors, albeit such competition will be friendly. The question arises, however—can we expect altruism from our friendly competitors? I doubt it. The synthetic elastomers have certain properties which transcend some of those of the natural product, but they cannot altogether replace the latter. Consequently, the two types, natural and synthetic, will be complementary to each other in the same way that plastics are complementary to metal. It will be essential, therefore, to refit the rubber plantations in our Far Eastern possessions as soon as we regain them. We cannot do otherwise since so much British capital is invested in rubber plantations and so many of the natives who will once more be under our care, depend for their livelihood on the preparation of natural rubber.

We hold, or will hold again, the monopoly of natural rubber production; the U.S.A. holds now and will hold then, the monopoly of synthetic rubber production. A case of sharing that which each has? Maybe, maybe not. America is experimenting with the production of natural rubber, and with the rubber substitute from the guayule shrub. In view of this most significant fact we, the British Empire, must set up a synthetic rubber industry or lose the race for economic equity. Not, I would emphasize, economic superiority, for that way trouble lies, but economic equity, the right to live and trade equally with all the great Powers of the world.

The reason that we have agreed that the U.S.A. shall undertake the preparation of the war-time synthetic rubber supplies is because of the vast quantities of natural petroleum gas available in their oilfields. These gases can be easily converted into butadiene by cracking and thence to the Buna series of synthetics. We have only meagre supplies of petroleum gas distributed throughout the Empire and cannot therefore compete in this field. Systematic surveys of the resources of the Empire will probably disclose fresh oilfields. In the meantime we can again fall back on coal.

Consult the chart shown in Fig. 1 for a moment. Three types of synthetic elastomer are shown:—Buna N, the co-polymer of butadiene and acrylonitrile; Buna S, the co-polymer of butadiene and styrene; and Neoprene, a polymerized chlorisoprene. These can be produced from coal by methods which are discussed later in this article.

Synthesis From High- and Low-temperature Combustion

Again, by low-temperature carbonization of coal the volatile products are mainly aliphatic and given proper conditions—those of temperature and pressure—it should be possible to arrange to get fractions of aliphatic hydrocarbons of sufficiently high molecular weight to enable them to be cracked to butadiene which is the precursor of the Buna series. The hydrogenation of coal to give motor spirit points a way also; such spirit can be cracked to give high-volatility spirit and butadiene provided the conditions chosen are correct. But much research will be necessary to establish these conditions; this research is an urgent and paramount necessity for the well-being of this Empire and should therefore be an Empire responsibility.

The preparation of the various synthetic rubbers from coal is shown schematically in Fig. 2. The raw materials are benzene, phenol and, once again, calcium carbide. The resultant synthetics are Neoprene, Methyl rubber, Isoprene rubber, Perbunan (and its cousins, Chemigum and Hycar OR), Butyl rubber, Buna S, the Thiokols and Koroseal.

The production of rubber from coal may sound romantic and yet it is quite feasible. Indeed, rubber has actually been found in some of the lignite mines in Germany; it occurs in thin, rubbery strands which on analysis prove to be fossilized vulcanized rubber. Such rubber may be fossilized remains of rubber-bearing shrubs or may have been produced by the alchemy of Nature. Neoprene would possibly pay best as a synthetic elastomer from coal since about 6 tons of Neoprene could be obtained from 10 tons of coal via the ubiquitous calcium carbide. Let us look at the economic side of this for a moment. The U.S. programme for 1944 (to supply the needs of all the United Nations) is for the production of 36,000 tons of Neoprene, 118,000 tons of Butyl rubber and 630,000 tons of Buna S. To prepare the amount of Neoprene envisaged above would necessitate the use of 60,000 tons of coal, but only the coke from that coal; the phenols, light oils and illuminating gas would still be available. Similarly, 80,000 tons of coal (in the form of coke) would be required to produce the butadiene required for 120,000 tons of Butyl rubber. The methods of producing the requisite amount of iso-butylene still needs to be worked out; this will be discussed later. Usually Butyl rubber contains about 20 per cent. of butadiene and 80 per cent. of iso-butylene, and it is on this basis that the following computation has been made. Buna S contains 25 per cent. of styrene and 75 per cent. of butadiene co-polymerized. Both of these constituents are available from coal as shown in Fig. 2. The styrene is obtained from the benzene and toluene fractions of the light oils and the amount of coal necessary to produce the requisite styrene to manufacture 630,000 tons of Buna S would be about equal to our annual production of coal (some 200,000,000 tons); the necessary butadiene would be producible from the coke residue from 1,250,000 tons of the coal used for styrene production. Obviously our coal industry cannot hope to produce enough coal to satisfy Buna S requirements. If we assume that one-third of the U.S. programme represents our peace-time needs (a fairly safe assumption), then the use of 150,000 tons of coal will give us 12,000 tons of Neoprene and the amount of butadiene required to make 40,000 tons of Butyl rubber. In addition we shall still have available 800 tons of coal-tar by-products capable of producing plastic materials. The essential industry is lacking, however, since we must have a carbide industry able to produce at least 200,000 tons of calcium carbide annually. This is not an excessively

enormous amount, and it is within the power of, say, Canada, to set up a large enough hydro-electric system to maintain such an output. The project we are discussing need not be insular; we can discuss it equally well within the framework of our Commonwealth of Nations.

Another possibility exists; benzene can be produced by acetylene polymerization. If such a process could be worked out on an economic basis (if, say, we could guarantee a 50 per cent. yield on the weight of acetylene) then via calcium carbide we could produce 2½ tons of benzene from 10 tons of coal, or the necessary styrene for 200,000 tons of Buna S from 120,000 tons of coal. Full-scale research on this problem is really worth while and should be undertaken as a State-assisted scheme. On the basis of the above figures this country could support itself in synthetic rubbers for the expenditure of about 300,000 tons of coal—less than 2 per cent. of our total production.

Subsidiary substances used in the processing of synthetic rubbers are also obtainable from coal: tack-producers of the coumarone resin type (see Figure 1), solvents such as toluene, chlorobenzene and cyclohexanone, and accelerators for use in vulcanizing. Mercapto-benzthiazole (Captax) and its oxidation product benzothiazyl disulphide (Altax) are the preferred accelerators and they can be produced from coal (benzene).

Production from Coal

How are all these substances produced from coal? The broad outlines are as follow:—

Calcium Carbide. This is made by heating a mixture of 56 parts by weight of quicklime and 36 parts of coke in an electric arc furnace at a temperature of 3,000 degrees C., arranged so that the quicklime and coke form liquid carbide which then flows away from the electric arc to enable a new charge to take its place. The molten carbide is tapped at the base of the furnace, allowed to solidify and broken up into lumps.

Acetylene. Calcium carbide reacts directly with water to form acetylene according to the equation

$$CaC_2 + 2H_2O \longrightarrow CH \equiv CH + Ca(OH)_2$$

The acetylene gas is compressed or dissolved in acetone and may be stored in steel cylinders, or it may be led through pipe lines direct to the reaction vessel in which it is to be processed further.

Neoprene. This synthetic rubber is polymerized chloroprene or chlorisoprene (2-chloro-1:3-butadiene) and was discovered by a team of research workers led by Wallace Hume Carothers, of the E. and I. du Pont de Nemours Co., of America, working on the chlorination of vinylacetylene, a substance which had been previously discovered by Nieuwland. Vinylacetylene, the basic raw material for the production of Neoprene, is a liquid boiling at 5 degrees C. which rapidly polymerizes on standing, first to a viscous oil and finally to a hard, resinous solid. The structural formula for vinylacetylene is $CH \equiv C-CH = CH_2$ and it is obtained by passing gaseous acetylene through an aqueous solution of cuprous chloride containing ammonium chloride. Under carefully controlled conditions excellent yields of the substance are obtained and the reaction has proved capable of large-scale industrial application. Carothers found that by treating vinylacetylene with hydrochloric acid in the presence of cuprous chloride, a liquid boiling at 59.4 degrees C. was obtained. This liquid was shown to be one of the chloro-isoprenes (2-chloro-1:3-butadiene), and was capable of polymerizing spontaneously to form Neoprene. The structure of "chloroprene," as it was termed, and the probable structure of Neoprene are respectively as follow:—

$$CH_2 = \overset{Cl}{\overset{|}{C}} - CH = CH_2 \longrightarrow [- CH_2 - \overset{Cl}{\overset{|}{C}} = CH - CH_2 - CH_2 - \overset{Cl}{\overset{|}{C}} = CH - CH_2 - CH_2 -]_n$$

The spontaneous polymerization of chloroprene is amenable to control and may be interrupted at the point at which the polymer has rubbery properties. The polymerization is usually carried out in an emulsion, and results in a creamy liquid resembling natural rubber latex.

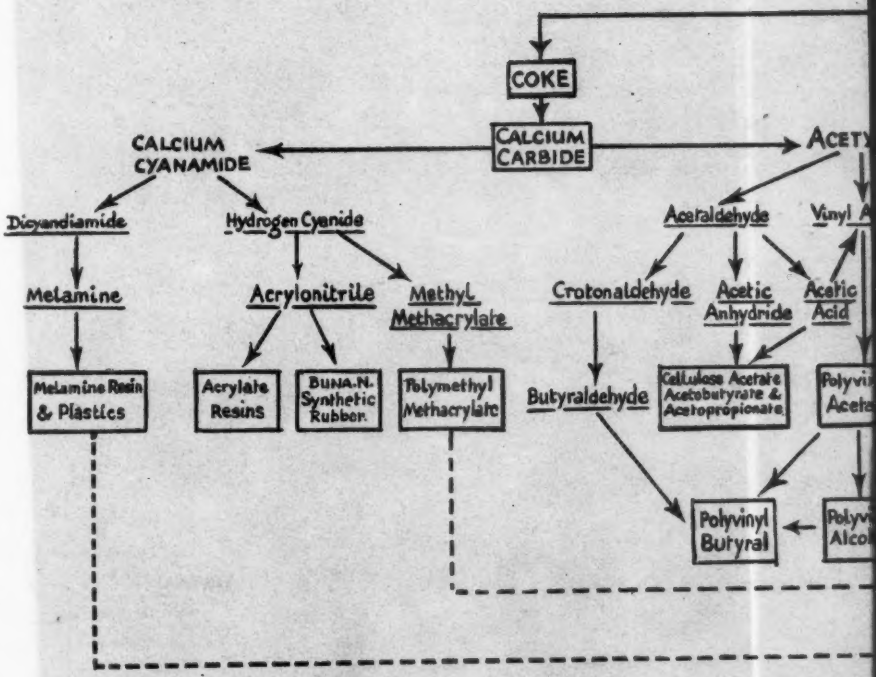
Neoprene is very similar in its properties to natural rubber and, in addition, is more resistant to the action of oils, motor fuels, air, sunlight and heat. It is a most useful synthetic and, as shown above, can be produced in quantity by means of simple chemical reactions, not involving any insuperable difficulties from an engineering point of view. The manufacture is, of course, covered by patents, but such difficulties can be resolved by working under licence of the original patentees. In addition, it is probable that systematic research would reveal similar polymers having properties akin to those of Neoprene. Such research would undoubtedly repay its cost in the shape of dividends and economic self-sufficiency.

Koroseal. This is a polymerized vinyl chloride, the basic raw material being obtained either by the direct addition of hydrochloric acid gas to acetylene, or by the removal of the elements of hydrochloric acid gas from ethylene dichloride. The polyvinyl chloride is plasticized by the addition of tricresyl phosphate, an ester of cresol obtained from coal-tar.

Butyl Rubber. This substance was developed as the outcome of a fundamental research programme carried out by the Standard Oil Co. It has been known for some time that double bonds represent a source of weakness in a molecule, and that in rubber only a fraction of the double bonds are saturated during the vulcanization process with sulphur. The remaining double bonds are open to chemical attack as, for instance, by ozone or oxygen, the rubber then deteriorating with age. The idea behind the research was to produce a synthetic elastomer having only the limited amount of unsaturation required for vulcanized goods. The answer was found in co-polymerizing olefines with small amounts of di-olefines. The general method of preparation is to react to a mixture of an iso-mono olefine such as iso-butylene with a di-olefine such as butadiene, the reaction being carried out at very low temperatures of the order of – 50 degrees C. in a solvent such as liquified ethylene gas. The reaction is of the Friedel-Craft type and utilizes a catalyst such as anhydrous aluminium chloride or gaseous boron tri-fluoride. We have seen that butadiene can be obtained economically from coal via acetylene prepared from calcium carbide. As shown in Fig. 2 the route to butadiene is through acetylene, aldol and 1:3-butylene glycol, the final stage being the dehydration of the glycol to butadiene. What of the other portion, iso-butylene? Can this be obtained from coal? Iso-butylene is a gas at normal temperatures and pressures and is one of the chief olefines obtained during the cracking of the petroleum; occurring in company with ethylene and propylene. It has been shown that by the low-temperature carbonization of coal, or by hydrogenation of coal, volatile mixtures of aliphatic hydrocarbons resembling petroleum are formed. It should be quite feasible to crack such a coal distillate in such a way as to give good yields of iso-butylene. This mono-iso-olefine is easily separated from accompanying gases by passing through cuprous chloride suspensions in kerosene, the gas being admitted to the suspension under pressure. Solid compounds of the olefines with cuprous chloride are formed and advantage is taken of the fact that the resultant complexes decompose sharply at differing temperatures and pressures to liberate the pure gases.

Butyl rubber may be prepared by the co-polymerization of isoprene and butadiene, both of which may be obtained from coal. By the elimination of excessive unsaturation, the major cause of rubber deterioration has been removed from butyl rubber, consequently it is highly resistant to chemical attack, oxidation, and the effects of such deleterious metals as cobalt, copper and manganese.

This substance represents the outcome of a research programme carried out by talented chemists backed by the financial resources of a large oil company and as such is a good example of the type of sponsored research pleaded for above. Think what results could be achieved by chemists in this country, backed by the resources of the Government.



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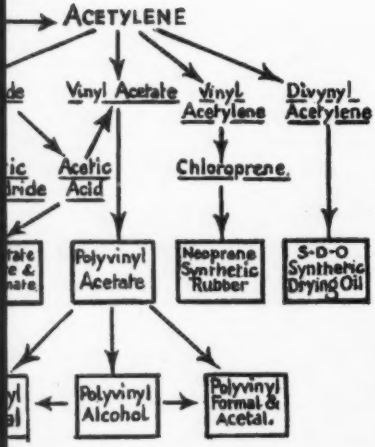
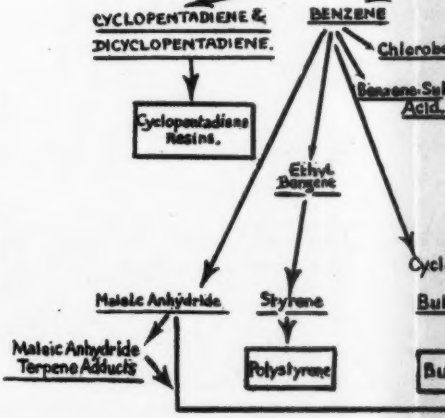

ACETYLENE
Vinyl Acetate
Vinyl Acetylene
Divynyl Acetylene
Acetic Acid
Chloroprene
Polyvinyl Acetate
Neoprene Synthetic Rubber
S-D-O Synthetic Drying Oil
Polyvinyl Alcohol
Polyvinyl Formal & Acetal.


CYCLOPENTADIENE & DICYCLOPENTADIENE.
BENZENE
Cyclopentadiene Resins.
Ethyl Benzene
Maleic Anhydride
Styrene
Maleic Anhydride Terpene Adducts
Polystyrene

THE D

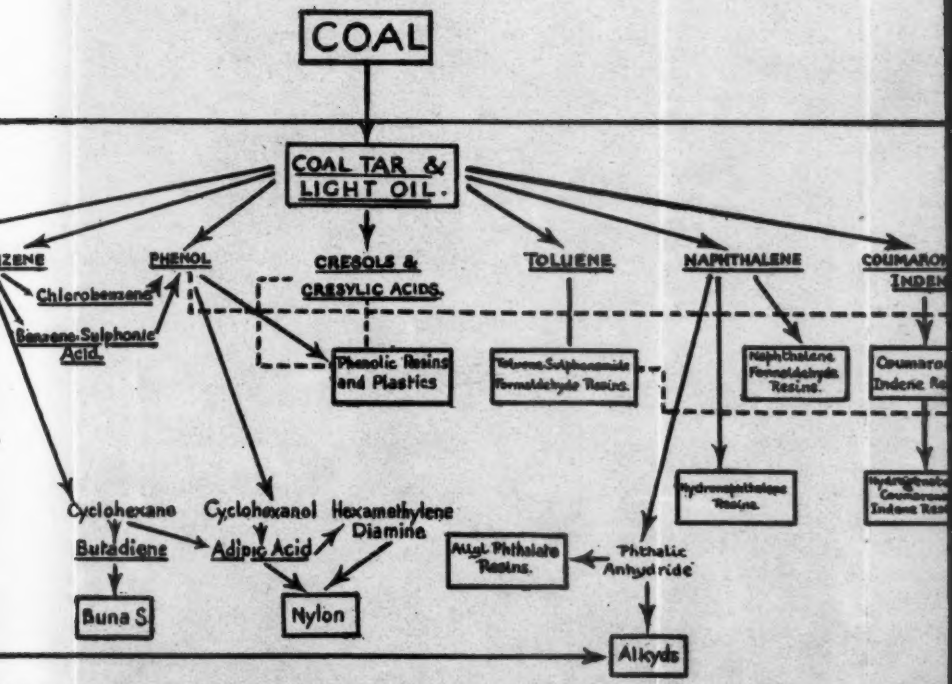
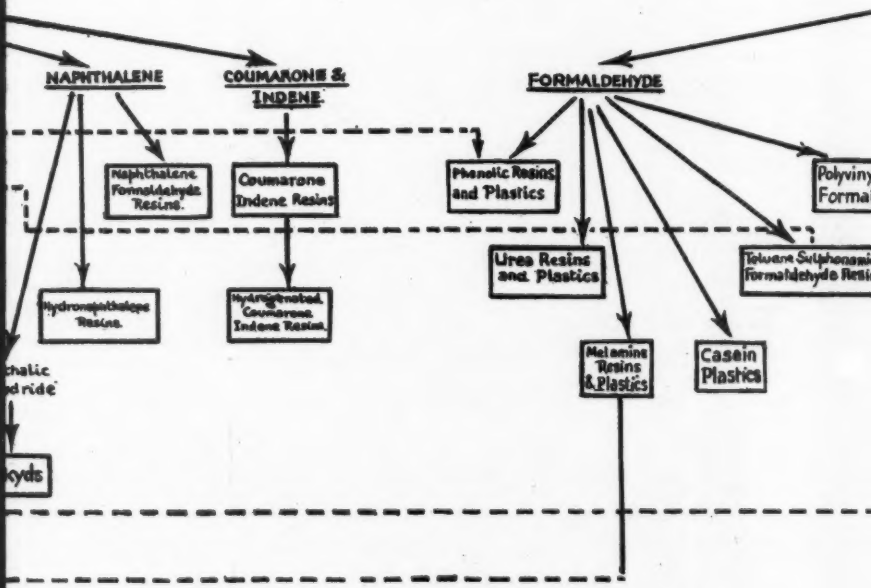
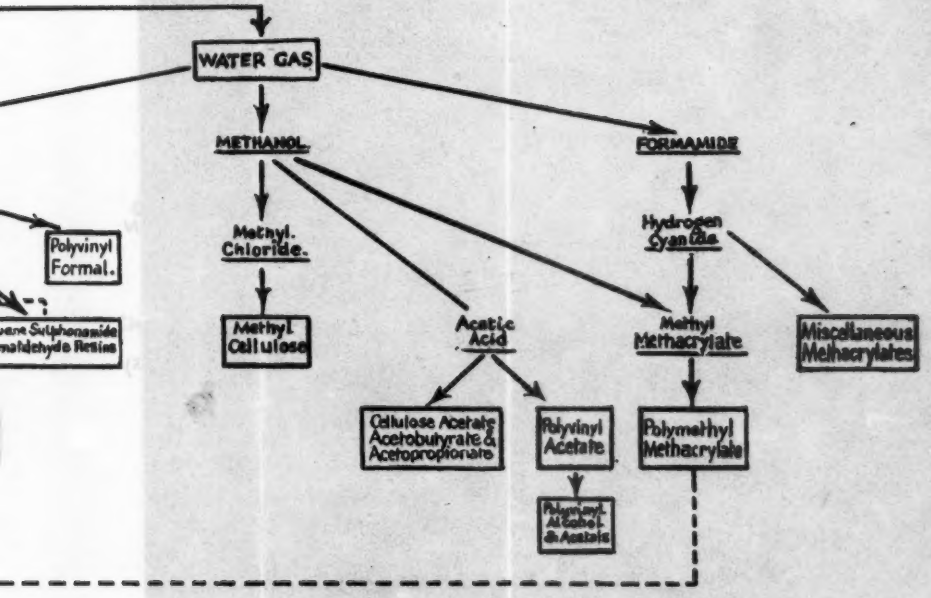


FIGURE I.

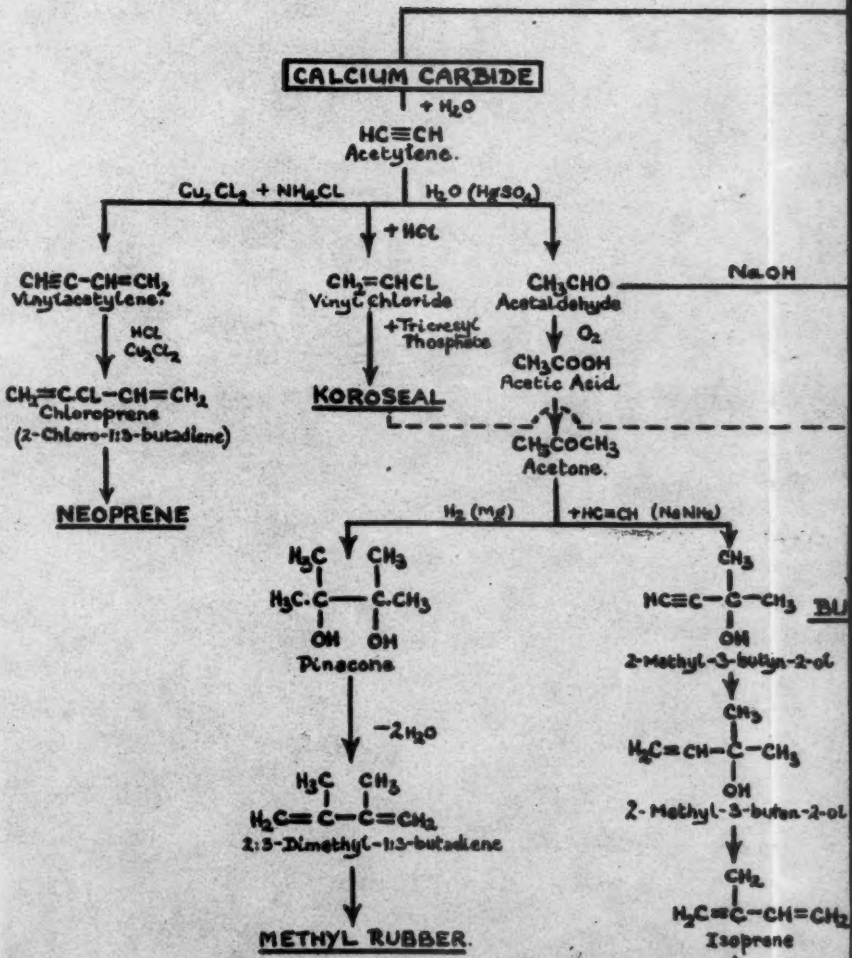
HE DERIVATION OF PLASTICS FROM COAL


NAPHTHALENE
COUMARONE & INDENE
FORMALDEHYDE
Naphthalene Formaldehyde Resins.
Coumarone Indene Resins
Phenolic Resins and Plastics
Polyviny Forma
Urea Resins and Plastics
Toluene Sulphonami Formaldehyde Resi
Hydronaphthalene Resins.
Hydrogenated Coumarone Indene Resins
Melamine Resins & Plastics
Casein Plastics
halic ydride
kyds

M COAL


WATER GAS
METHANOL
FORMAMIDE
Polyvinyl Formal.
Methyl Chloride.
Hydrogen Cyanide
Methyl Cellulose
Acetic Acid
Methyl Methacrylate
Miscellaneous Methacrylates
Cellulose Acetate Acetobutyrate & Acetopropionate
Polyvinyl Acetate
Polymethyl Methacrylate

COKE
CALCIUM CARBIDE
Hydrogen Cyanide
Acrylonitrile
Acrylate Resins
Melamine Resin Plastics



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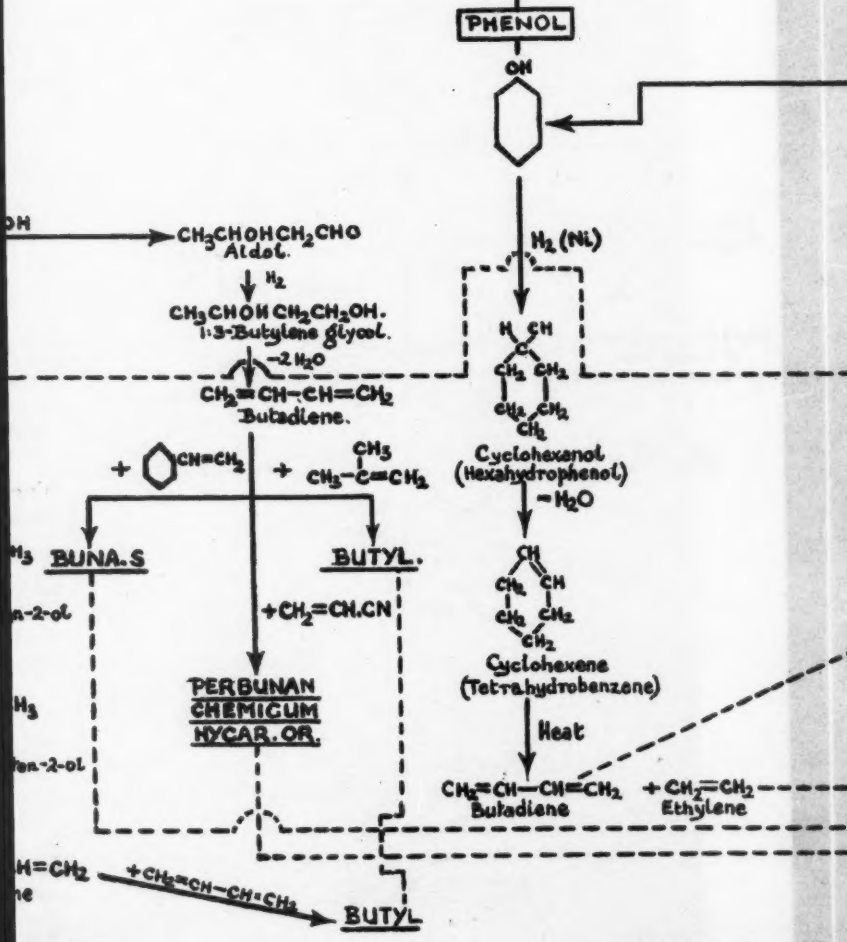
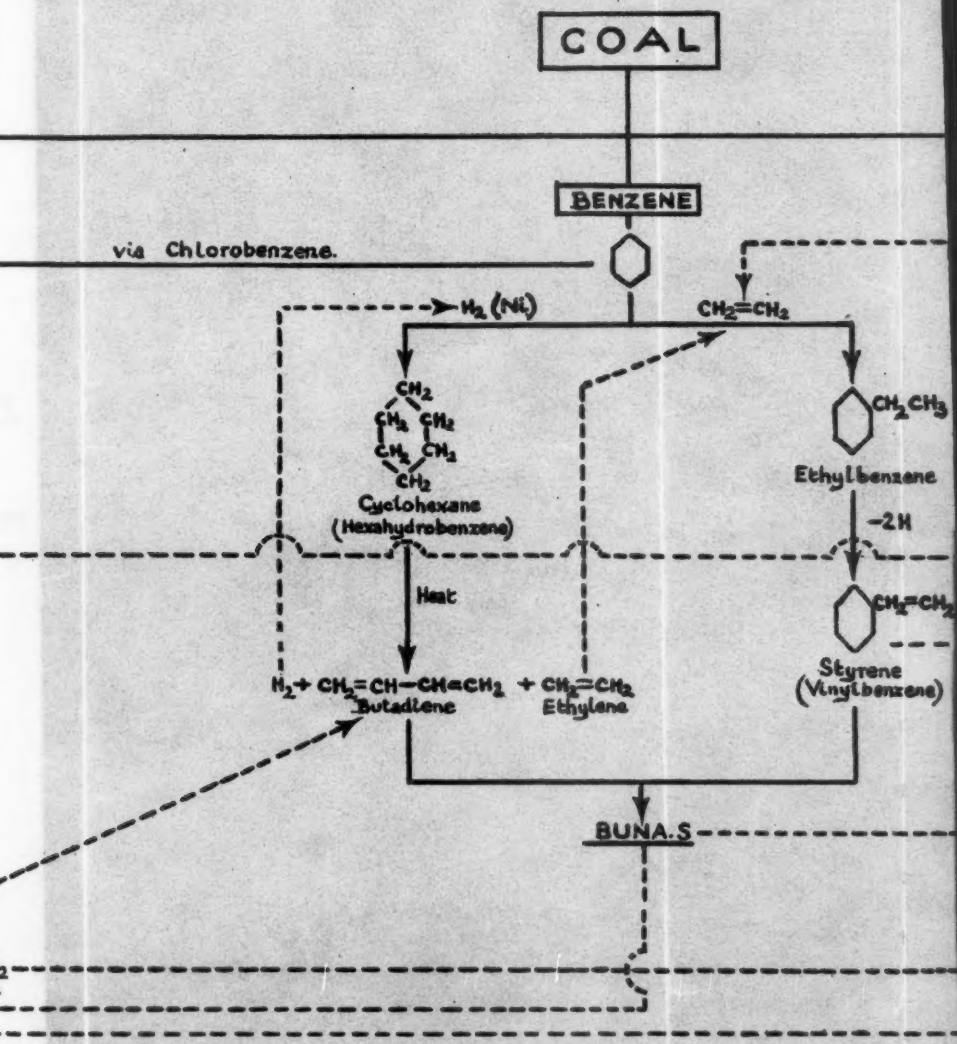
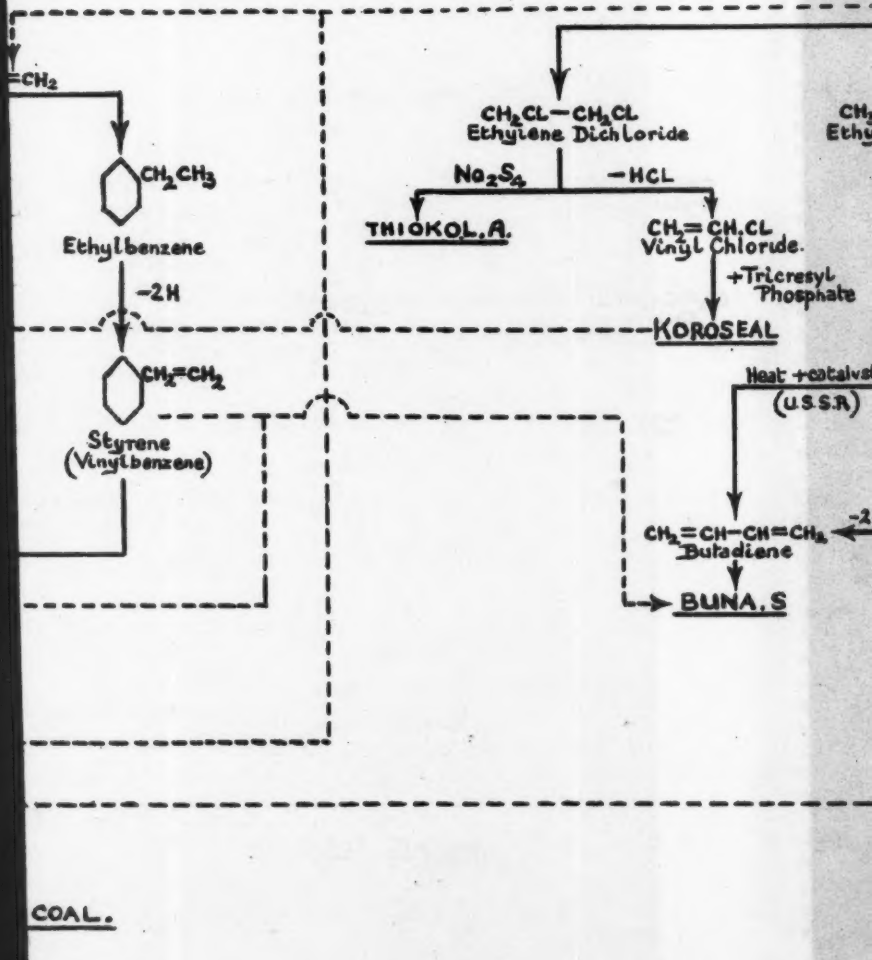
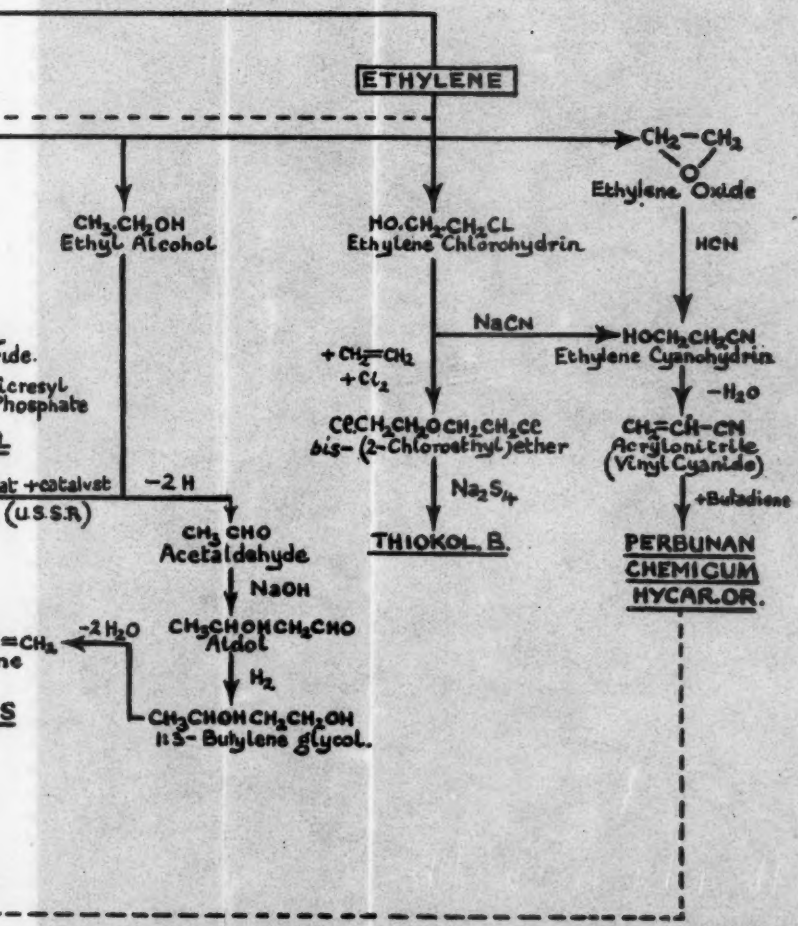

PHENOL
OH
H_2 (Ni)
$CH_3CHOHCH_2CHO$
Aldol.
H_2
$CH_3CHOHCH_2CH_2OH$.
1:3-Butylene glycol.
$-2H_2O$
$CH_2=CH-CH=CH_2$
Butadiene.
Cyclohexanol
(Hexahydrophenol)
$-H_2O$
BUNA.S
BUTYL.
$+CH_2=CH.CN$
PERBUNAN
CHEMIGUM
HYCAR. OR.
Cyclohexene
(Tetrahydrobenzene)
Heat
$CH_2=CH-CH=CH_2$
Buladiene
$+CH_2=CH_2$
Ethylene
$+CH_2=CH-CH=CH_2$
BUTYL
RUBBER

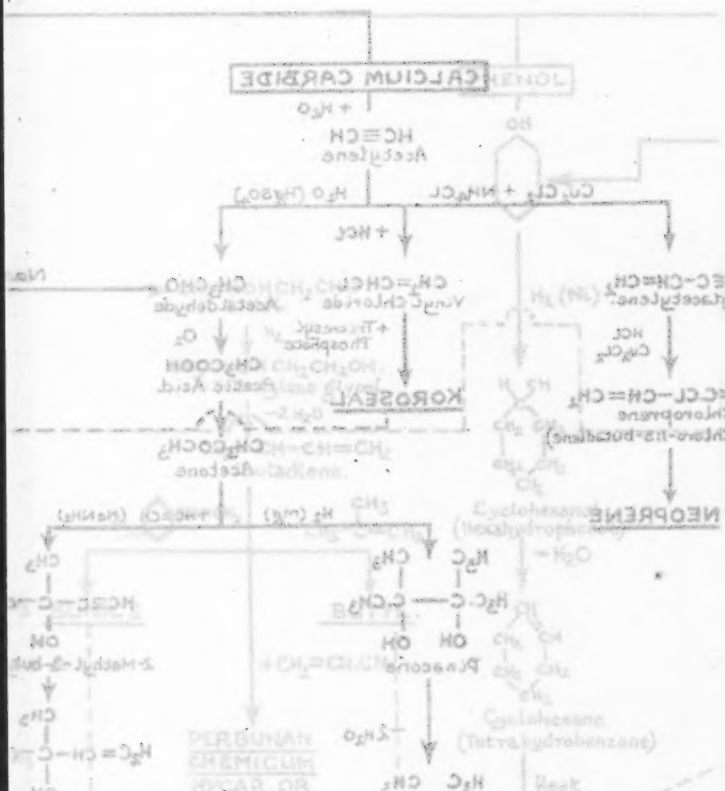
FIGURE 2. Syn



2. SYNTHETIC ELASTOMERS (RUBBERS) DERIVED FROM COAL.


=CH₂
CH₂CH₃
Ethylbenzene
-2H
CH₂=CH₂
Styrene
(Vinylbenzene)
CH₂CL—CH₂CL
Ethylene Dichloride
Na₂S₄
-HCL
THIOKOL.A.
CH₂=CH.CL
Vinyl Chloride.
+Tricresyl
Phosphate
KOROSEAL
Heat +catalyst
(U.S.S.R)
CH₂=CH—CH=CH₂
Butadiene
BUNA.S
COAL.


ETHYLENE
CH_2-CH_2
O
Ethylene Oxide
$CH_3.CH_2OH$
Ethyl Alcohol
$HO.CH_2.CH_2CL$
Ethylene Chlorohydrin
HCN
NaCN
$HOCH_2CH_2CN$
Ethylene Cyanohydrin
$+CH_2=CH_2$
$+Cl_2$
$-H_2O$
$CeCH_2CH_2OCH_2CH_2Ce$
bis-(2-Chloroethyl)ether
$CH_2=CH-CN$
Acrylonitrile
(Vinyl Cyanide)
$Na_2S_{/4}$
+Butadiene
THIOKOL. B.
PERBUNAN
CHEMICUM
HYCAR.OR.
-2 H
(U.S.S.R)
CH_3CHO
Acetaldehyde
NaOH
$-2H_2O$
$CH_3CHOHCH_2CHO$
Aldol
H_2
$CH_3CHOHCH_2CH_2OH$
1:3- Butylene glycol.


CALCIUM CARBIDE
+ H_2O
$HC \equiv CH$
Acetylene
$CuCl_2$ + NH_4Cl
H_2O (H_2SO_4)
+ HCl
$CH_2=CHCl$
Vinyl Chloride
$CHC-CH=CH_2$
Vinylacetylene
$CH_2=CCl-CH=CH_2$
Chloroprene
(2-Chloro-1:3-butadiene)
CH_3COOH
Acetic Acid
CH_3COCH_3
Acetone
NEOPRENE
$H_3C-C(OH)(CH_3)-C(OH)(CH_3)-CH_3$
Pinacone
$H_2C=C(CH_3)-C(CH_3)=CH_2$
2:3-Dimethyl-1:3-butadiene
METHYL RUBBER
ISOPRENE
FIGURE

Buna Rubbers. The Buna synthetics take many forms. They may be either self-polymers of butadiene—the polymerization being brought about by the agency of metallic sodium—or they may be co-polymers of butadiene with such substances as styrene or acrylonitrile. Reference to the chart (Fig. 2) shows that Buna S is derived from butadiene and styrene, and that Perbunan, Chemigum and Hycar OR are co-polymers of butadiene and acrylonitrile. We have discussed Buna S previously in this article and have shown that it can be derived from coal provided a better route to benzene is discovered. The acrylonitrile co-polymers are best exemplified by reference to Perbunan, since more data is available respecting this substance than there is respecting Chemigum and Hycar OR.

Perbunan contains about 25 per cent. and Perbunan Extra about 35 per cent. of acrylonitrile respectively. Acrylonitrile may be prepared by several general methods: (a) the direct addition of hydrocyanic acid to acetylene in accordance with the equation

$CH \equiv CH + HCN \longrightarrow CH_2 = CH.CN$

the yields, however, being rather low; (b) by pyrolysis of acetaldehyde cyanohydrin $CH_3CHO + HCN \longrightarrow CH_3CH(OH)CN \longrightarrow CH_3CH(O.CO.CH_3)CN \longrightarrow CH_2 = CH.CN$ through the acetoxy compound. The yields by this process are said to be very good. Chart 1 shows that acetaldehyde is produced by passing acetylene obtained from calcium carbide through sulphuric acid containing mercuric sulphate as a catalyst. This method of manufacturing acetaldehyde is a continuous process giving a very pure product in good yield. The necessary hydrocyanic acid is obtained by way of calcium carbide —> calcium cyanamide —> calcium cyanide —> hydrocyanic acid. We have shown that butadiene is also obtainable from coal and hence we have an all-coal synthesis of Perbunan synthetic elastomers. (c) From ethylene chlorohydrin. Ethylene combines directly with hypochlorous acid in aqueous solution to give ethylene chlorohydrin, a syrupy liquid which reacts with sodium cyanide to give ethylene cyanohydrin. The latter compound is then dehydrated by heating with potassium hydrogen sulphate to yield acrylonitrile. (d) Ethylene chlorohydrin reacts easily with alkali to give ethylene oxide which combines directly with hydrocyanic acid to form acrylonitrile.

Perbunan is formed by co-polymerizing the two reactants, butadiene and acrylonitrile, by the emulsion method. It has outstanding resistance to the effects of oils, greases, petrol and other organic solvents. It is superior to natural rubber in resisting solvents, abrasion, oxidation and ageing, but is inferior in sunlight and resistance to chemical reagents.

Methyl and Isoprene Rubbers. Both of these elastomers are derivable from coal as shown in the chart in Fig. 2. The reactions involved are, however, complex and tortuous and it is improbable that any serious attempt to produce these substances by this route would be an economic success. It is of interest to note that in the 1914-1918 war, German chemists succeeded in producing about 300 tons of Methyl rubber via pinacone derived from acetone. Isoprene rubber approaches natural rubber more closely than any other synthetic elastomer, but isoprene is not easily synthesized, in fact the best yields of isoprene are obtained by the destructive pyrolysis of natural rubber.

(To be continued.)

Production Bulletin

We do not know if the Ministry of Labour and the Ministry of Production will exist after the war, but we hope the Production and Engineering Bulletin they issue will not disappear too. It is an invaluable bulletin, and, in the usual words of the reviewer, should be on every works manager's shelf. The subjects range far and wide and the December issue contains excellent articles on the subjects of "Quality Control in Operation," "Efficiency in Factory Heating," "Simplifying Machine Setting," "Industrial Dermatitis," "Shepherds Who Make Steel," "Repairing Armoured Vehicles," "How Railways Go to War," etc.

Designing for Plastic Moulding

by W. M. HALLIDAY

Being the first portion of an article discussing practical designing aspects involved in the development of moulded articles.

The modification of existing designs of parts in other materials and fashioned by different processes is often necessary in order to obtain economical advantage of the moulding process.

Simplification of design of a projected component will often effect reduction in costs, increase in mould life, greater serviceability of product, and increased production.

But the maximum economies and benefits inherent in plastic moulding will best be ensured by following a policy of Designing Components for Plastic Moulding, rather than simply modifying or adapting previous designs.

Every stage and feature will then be specifically planned for mouldability and reference of part to desired functions or purposes, regardless of previous design considerations possessed by a non-plastic or unmoulded article.

Usual Method of Design Formation

THROUGHOUT every branch of the whole moulding industry it is a very noticeable fact that the basic elements and features of the design of a moulded product generally have their origin with the prospective user in the following manner.

Usually he requires to effect a saving, or improvement, by substituting a component or components made in either metal, wood, porcelain, or sheet materials, for one in a plastic material. He often has a vague idea of the practical benefits likely to be gained by the use of a plastic moulding, such as exact duplication of shape and essential sizes, elimination of machining, improved appearance, etc.

Accordingly, he avails himself of the assistance of a moulding manufacturer, to whom he submits the proposition, stating his requirements, which most often consists of passing along a sample part, or drawing, or both, for the guidance of the moulder.

Now such a sample or drawing will generally be a component it is desired to substitute, thus being of such a design, shape, and featurization certainly not intended for reproduction by any process similar to that of plastic moulding.

In many instances the moulder is expected to reproduce this kind of design as the prospective user is unable to envisage another form as being applicable to his purposes.

It is very much open to doubt whether this practice is one which always secures the best practical results in the way of the user being supplied with a moulding as near as possible perfectly suited to meet all the manufacturing and service conditions involved.

Furthermore, it is also questionable whether it ensures him being supplied with mouldings at the most economical cost, whilst one is sure that the degree of satisfaction afforded to both interested parties to the transaction is very often far less than is desirable.

As a preliminary, then, to this discussion, and also in order to provide some guidance to potential users who will be, as already explained, the developers of chief features of design, the writer here lists some of the main apparent reasons, which, in his opinion, are the cause of moulded articles developed in this manner possessing design features which fail to give satisfaction or fullest reliability and service when the article is placed in use. Careful consideration of the following points will indicate the need for closer attention being given to the first stages in the evolution of a design so that it may be better adapted in form and features.

Lack of Knowledge Affects Design of Projected Mouldings

By the very nature of present-day industrial specialization, most potential

users engaged in widely divergent forms of business and production, wishing to utilize the advantages offered by plastics, actually have but slight knowledge of the technique, processes, methods, and especially the advantages and restrictions of the process or materials employed.

This lack of knowledge must inevitably result in the user very often stipulating the provision of features, etc., in a moulded article (sometimes with great insistence) which may be exceedingly difficult or costly to reproduce.

If such features are insisted upon in face of the advice of the moulder such action may become the source of friction, dissatisfaction, increased costs, an unsatisfactory article and general failure to realize the possibilities of plastic moulding.

On the other hand, design features may be insisted upon which are quite capable of being cheaply produced, but are of such a type, shape, or quality that the moulder will know they will not give proper service when placed in operation or use. This may be because of inadequacies of the materials, or mechanical or physical failures.

Often it is to be noted that the degree of co-operation between the user and his moulder is neither full, free, nor unbiased, with the result that the latter partner may be hindered and prevented from developing the best design of moulding consistent with the desired functions it has to perform.

If greater freedom and more latitude were afforded him the manufacturer very often would be enabled to create a design perhaps on entirely new lines to that formerly employed in a non-plastic component. Such a design would almost certainly be more in harmony with the fundamental factors of mouldability, economy of material, and costs, and a better suited component. Other advantages such as appearance, durability, etc., would also be obtained.

This, of course, is one of the chief roles which the moulding manufacturer can play, and his influence upon design development can and should be very valuable. But the possibilities in this regard depend upon the degree of freedom on design matters permitted by the would-be user, who in turn should possess sufficient knowledge of the moulding processes to enable him to understand and appreciate the difficulties confronting the moulder.

Mouldings Are Not Purchased by Weight

Many prospective users very often overlook the fact that plastic mouldings are nearly always quoted and charged by the manufacturer on a cost per piece basis, and not by weight as is the customary practice with regard to metal castings, for instance. At first sight this may appear unusual because a very lightweight moulding may be far more expensive than one several times heavier. It is important that one making his first introduction in the buying and use of plastics should understand the reasons underlying this practice, because knowledge of same will also play its part in the determination of the best design features to be incorporated.

The weight of a moulded article is not the prime consideration affecting its cost, because of the method of its manufacture. The parts are produced by means of a steel, or alloy-steel, mould, and thus the time necessary for operating the mould each cycle, plus material, plus labour, and a number of subsidiary machining operations combine to determine the cost of the part. Where the production time is lengthy for any given reason then obviously a smaller number will be produced per period and costs must accordingly be increased. The moulder in quoting sometimes spreads out the cost of the mould and other tools over the whole quantity of parts ordered, whilst another method is to quote a separate charge for moulds, this usually being a percentage only of their full cost, which figure is applied to first batch of parts ordered. In both cases, incidentally, exclusive use of such moulds, even though the client may not have paid the full cost, is understood to be the client's prerogative.

Reduction in Weight is Not Always Economical

It should be pointed out at this stage that design, modifications or alterations aiming chiefly at reduction of weight may not always prove economical as regards prices, or suitability of component to withstand service conditions. In fact, in some cases insistence upon weight-reducing action may incur an increase in costs due to the creation of additional moulding difficulties, thereby causing a slowing down of production rate.

Such reduction in weight may also involve either partial or complete failure of the part to meet the mechanical, electrical, or other requirements. Or it may lead to a drastic loss of dimensional accuracy or control of essential sizes by allowing the lighter moulding to undergo excessive warpage. These, by the way, are but a few of the troubles likely to arise for the moulder by a moulded article of unnecessary or unsuitable lightness.

Cost of Mouldings Depends Upon Complexity of Design

It is also very necessary to realize that the price of a plastic moulding varies directly, and importantly in many instances, not only with the quantity ordered, or the total weight of material needed for their manufacture, but also with the degree of complexity of the design. As this latter factor increases in intricacy the resultant number of manufacturing problems presented to the moulding chemist and engineer will be increased, often in number as well as magnitude. Generally speaking the more complex the moulding has to be, the more complex also will the mould have to be, resulting in slower production speeds, as well as greatly increased initial mould costs over those necessary for a simple design of moulding and a correspondingly simple mould construction.

There are many plastic mouldings being made at the rate of upwards of 1,000 per day, costing only a few coppers each, and much less each per weight of material used. But on the other hand there are also a large number of components moulded at the rate of only two or three hundreds a day yet costing upwards of 1s. 6d. each.

Such price disparity is due not so much to the added size or weight of the latter kind as to the complex design and the consequent need for an intricate and very expensive tool for producing them.

Thus in this aspect of the matter the potential user will readily appreciate that the design features stipulated by him in the beginning may exert a very potent effect upon the costs later charged up to him.

Undesirable Design Features Adversely Affecting Production

Many designs of components upon examination are found to be unsatisfactory from the producer's angle because of numerous obstacles inherent in the design which militate against good working practice and rapid production.

The forming steel moulds employed in plastic moulding have to follow certain well-defined forms and principles of design and construction. Moreover, they are in fact precision tools of a high order of accuracy and workmanship whose manufacture ordinarily displays considerable ingenuity on the part of their designer, with great skill and experience of the mould maker combined with long training and use on the part of the operator.

Therefore, any projected design forms necessitating a complicated mould may very easily add another £50 to the cost of the tool. Or, to put it conversely, the elimination of certain features may not only simplify the moulded part but also greatly diminish the complications of the mould thereby immediately reducing the cost of the mouldings as well as mould charge.

For this reason, amongst others, it is always advisable for the would-be user to be chary of insisting too strongly upon the provision of features, etc., which the moulding engineer advises as being unsuitable, uneconomical, or difficult.

It will be advisable and useful to mention some of the more commonly

encountered kinds of undesirable design features which are found often to lead to unnecessary and expensive mould complications. They will furnish some sort of guide for indicating the kind of thing to avoid when laying down the main essential outlines of a moulding design. These are as follow:—

(a) **Overall dimensions.** Very often a design is developed in which one or more of the overall dimensions are difficult to reproduce. The maximum nowadays commercially possible or suitable are not strictly limited. Instead, much depends upon the capacity of the moulding presses or injection machines available. But as a general rule a moulded article will prove prohibitively expensive from a production standpoint if its overall dimensions are in excess of about 24 ins. by 15 ins. by 15 ins., with a wall thickness not more than .375 in.

With a thicker wall the curing time needed for material will usually be so long that costs are very disproportionately increased.

(b) **General Configuration.** Care should be taken to ensure that the general outlines and surfaces of the intended moulded part are uniform, regular, and symmetrical. Unsymmetrical curved surfaces, for example, will be found exceedingly difficult to reproduce both on the finished part, and especially in respect of the mould matrices. Lack of thought on such a detail may, and often does, involve considerable manufacturing difficulty for the mould engineer. In addition the shape may be of such a form as to render withdrawal of the finished product from its mould difficult. This is, perhaps, the first principle to be remembered in connection with the fabrication of plastic moulded parts. The design should be such as to permit the finished article to be easily, rapidly, and safely removed from the mould.

(c) **Irregularity of wall thickness.** Here again in this instance the moulder is often occasioned considerable difficulties due to warpage, distortion, ejection troubles arising from unequal wall section, sudden interruptions, or thickenings of cross-sectional area. Wherever possible, uniform, and regular-shaped cross-sections of a part should be maintained, as this will result in more uniform shrinkage, accordingly lessening the strains both during the actual moulding and later when the product is placed under service conditions. In the case of thermosetting plastics irregular cross-sections of the design will increase the moulding cycle to that required for the complete polymerization of the heaviest section. In the case of the thermoplastic materials the cooling time will be correspondingly increased by the presence of unequal thickness of walls.

(d) **Angle of wall inclination.** Removal of a finished component from its mould will be facilitated if the design is such as provides for ample inclination of the walls. The greater this angle can be made the less tendency there is for the part to stick or "hang up" when being withdrawn from mould cavity. Good general practice allows from 3 to 5 degrees. It is unwise usually to stipulate an inclination smaller than .004 per in. of vertical side. Such "draught" will also promote stricter control over important dimensions by making ejection operation quicker and reducing warpage.

(e) **Type, extent and number of undercuts.** As far as practicable a design should avoid the provision of undercut portions in the sides of a part. Where these are absolutely necessary they should be positioned in such a way as to follow line of draw of press ram. Otherwise additional cores and side core-drawing means will be required on the mould, which, of course, may prove an expensive complication.

(f) **Number and size of cored holes, etc.** Very often a design involves elaborate coring for making holes of exceptional depth, diameter or shape. Generally, the more cores embraced by a mould the slower will be its working cycle and the greater will the finished moulding cost be.

(g) **Degree of accuracy.** Very often a moulding design calls for close tolerance in regard to certain dimensions, hole diameters, or spacings, which actually would

be quite satisfactory if greater latitude were allowed. Therefore in evolving a design careful attention should be given to this point lest too strict limits are laid down for the moulding manufacturer, as these will cause him extra production problems.

(h) **Type and number of inserts.** This is another point often calling for close consideration. In some cases inserts are provided when the more satisfactory and inexpensive course would be to affix them after moulding by one of the more usual machining operations, in the interests of mould simplicity of construction and working.

(i) **Flash formation and removal.** This is an aspect of design calling for careful attention, otherwise the parting line of mould forces may be located in such a manner, because of design and shape of part, that a thick flash is unavoidable. Should this arise added costs will be incurred in its removal, there may be the risk of unsightly spots on surface of moulded part, and a weakening of wall strength at the point of thick flash which may prove harmful when component is placed in use.

(j) **Auxiliary machining operations.** Here again moulding design can usually be arranged in such a manner as will obviate the need for costly and protracted auxiliary machining requirements on the moulded part, thereby securing economies. Holes of very small diameter should be drilled, for instance, rather than cored, as slender core pins do not make for smooth operation of the mould. Such holes, etc., should be so arranged as to be capable of drilling or tapping by means of a fixture or jig, thus ensuring uniformity and accuracy with cheapness.

All these factors, then, are exceedingly important, materially affecting mould design, mouldability of article, and ultimate costs. Design forms, therefore, should be chosen duly cognizant of the effects of these factors, and at a later stage several of these points will be discussed in more detail and illustrations given of practical ways to adopt for overcoming such difficulties.

Design Modification and Scope Permitted the Moulder

The question will be asked, what is a desirable degree of latitude which should be permitted the moulder in the way of modifications to a customer's design?

Very often the moulder, after considering the submitted sample or drawing, will envisage substantial changes or simplifications in the interests of production. Or he may develop an entirely new design possessing features far more in conformity with best moulding practice, and with desired requirements. In such circumstances the client should give sympathetic ear to the reasons advanced for such drastic alteration or fresh departures in design, and endeavour to shed all his preconceived design notions centred upon obsolete designs of article in non-plastic materials.

Generally, then, the moulder should be free to depart from submitted designs in order to exercise his role to the fullest extent.

There must be a considerable number of plastic moulding designs which are modifications of forms developed without reference to moulding, giving indifferent service, and which could be superseded without extra cost by entirely new designs.

Therefore the intending user of a plastic moulded part, when arranging design, should ask himself whether economies are to be gained by adhering to or departing altogether from previous design features and characters.

Design Also Determines Choice of Moulding Machine

In yet another direction it is advisable for the intending user to give attention to design. This relates to the press or moulding machine required for conducting production of agreed part. This matter, it should be appreciated, is of some importance and concern to the moulding engineer, as affecting his costs and rate of output.

Where, for instance, the overall dimensions of a project enable it to be produced upon an entirely automatic press,

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or in the case of an injection moulding, upon a machine, then obviously, other factors being equal, on a moderately sized batch useful savings will arise due to the increased rate of output, lower labour costs, and so on. If, on the other hand, the design features are such as to necessitate it being produced upon, say, a semi-automatically operated press or machine, or one of exceptional pressure capacity but slow speed, then the rate of production will be reduced.

It should be remembered that the trade moulding manufacturer has to install numbers of batteries of presses or machines, or both, these ranging in capacity as to pressure, length of ram stroke, size of platens, operating speed, volume of delivery per shot. He has to equip his works for producing mouldings of any size, or shape, lying within the specialized range or class he wishes to cover.

Thus designs of moulded articles incurring deep cored holes may require production upon a much slower operating press. By a careful adaptation or selection of design forms, such as shortening the depth of required hole, or allowing increased taper on its sides, the user may easily make it possible for the moulder to make the part upon a smaller yet faster press, thereby increasing production rate, decreasing costs without any sacrifice in the essential features or functioning of finished product.

Good general rules to follow in this connection comprise the following. All portions of a moulded article required to be hollow should be as shallow in depth as possible. Such cored parts to be located in line with stroke of press ram, that is vertically in most cases. Overall dimension should be arranged as far as possible to provide a mould capable of being fixed properly to platens of press. Where the sizes of the former are such as to involve considerable portions overhanging sides of machine platens, there is a danger that mould blocks will become distorted, that thick flash will develop on finished parts, and that the smooth working of mould blocks will be retarded due to sticking of dowels, etc.

Principles for Laying Out Design for Plastic Moulding

All that has been previously written is in the nature of general guiding observations regarding the obstacles, limitations and advantageous points to be considered when designing for modifying or simplifying an existing form is being undertaken. As already emphasized, whilst the moulding manufacturer undoubtedly plays a very valuable part in suggestion of design changes, adaptations, improvements, etc., in the interests of better mouldings and cheaper production, it is far preferable, wherever possible, to embark upon design developments free from the limiting influences of existing designs to which the user may have become habituated by long contact and use of non-plastic articles.

As the preliminary step, then, to discussion upon this latter important aspect it will be advisable to detail some of the material advantages which the writer has found to be derived from following such a designing policy.

(1) Generally, designing specially for the moulding process will ensure a better shape, function and serviceability of the finished part. This will arise because every desired characteristic of a projected moulding can be carefully chosen, related to other factors, or to mouldability so as to obtain the maximum benefits in each respect. Thus the moulder will find himself confronted with less problems, production will be smoothed out, costs lowered and a more satisfactory moulding is likely to result, with all-round contentment.

(2) Reduced costs will usually arise from several connected sources in the case of such a design. Thus mould constructions may be simplified, leading to easier operation, whilst ensuing finishing operations may be reduced in number or scale. Materials also will be saved.

(3) Finish and appearance can usually be improved because of greater attention being devoted to such matters as location of feeders, arrangement of cross-sectional area, wall thickness, these affecting curing time and surface finish of product.

(4) Mould life may very often be considerably increased, which in itself will be the cause for appreciable savings on a large batch of parts.

(5) Another important point deserving recognition by the user is that generally an article specifically planned for plastic mouldings will prove stronger and more durable than one developed without complete reference to the needs and limitations of the process. Numerous examples illustrating this could be given, i.e., thin box-like articles previously made in cast iron, whose walls were of very thin section, gave trouble by the readiness with which cracks and fractures developed. When a substitute plastic moulded box was furnished, even though the wall thickness was still less than the iron part, greater strength and reduced brittleness were secured. By ribbing or providing beadings great increase in strength can usually be secured without adding greatly to the weight of a moulding.

(6) Reduction in the number of components can usually be more readily planned. If the designer sets out to inaugurate a new design for a moulding free from preconceptions linked up with previous designs in non-plastics, he will often find it possible to incorporate two or more separate components into a single plastic moulding. Where this course can be adopted obviously very considerable savings may be effected due to such simplification of three designs into one composite form, avoidance of three moulds, and the elimination of a number of secondary operations such as flash removal, drilling, assembling, etc., which previously would have to be performed on the three separate parts.

Admittedly, in order to promote such useful practice the originator of design, be he prospective user or moulding manufacturer, requires to have a complete picture not only of the single unit or units but also of their precise relationship with each other and rest of assembly into which they are to be fitted. He needs to know also the exact functions, purposes, needs and conditions imposed, which such parts will have to withstand.

Whilst many well-known plastic moulding assemblies could be evidenced to illustrate the practical advantages and economies to be gained in the above manner; on the other hand, whilst it is always advisable to consider if and how the projected plastic moulding can embrace a number of units, there are occasions when it may be discovered that a contrary procedure is to be preferred.

In such cases the designer will realize that if the part has to be moulded in one piece it will be of such a complexity as to render necessary a very intricate and costly mould, with resultant increased costs and slower production. Thus in such instances the designer will strive to fashion two or three separate components each of a simple form so adapted for easy and rapid assembly together.

Multiple Cavity Moulds

Many cases will arise in this connection where the moulding designer may find it practicable to make a single mould possessing a number of cavities, each to provide a differently shaped component. Thus with each cycle of operations of mould a complete set of parts needed for the whole assembly will be produced. This will assist towards economical working by providing a balanced output, avoiding shut-downs for change over of moulds, and in storage of finished parts.

(7) Accuracy. Generally speaking, a moulded article, designed and planned specifically for the moulding process, enables closer control to be exercised over essential accurate dimensions and features. As previously hinted, this advantage will accrue because such matters as wall thickness, core location, ejector mechanisms, etc., will also be considered in reference to this end. As a result warpage, distortion, and variations will be kept to lowest levels.

(8) Reduction in waste and scrap. Yet another valuable aspect of planning design for moulding and its effects upon cost reduction lies in regard to scrapped parts and manufacturing wastes. Scrap will be reduced because accuracy can be closer controlled, faults and errors will

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be kept at a minimum. On large batches the savings alone from this source may prove substantial.

(9) Saving in materials. Very often because of the mechanical and physical features possessed by most plastics and the development of special types of material applicable for electrical, insulating, mechanical, acid-resisting qualities, the moulder will be enabled to plan the features of a project with special reference to meeting those requirements. Thus materials may be saved, or a more suitable type or grade of powder employed resulting in a superior product better able to stand up to service requirements.

(10) Subsidiary machining operations. Another well-worth-while point which the writer has found to result from such a planned design policy as here advocated is that the moulding engineer will often be permitted to eliminate or simplify auxiliary machining operations entailed to finish the moulding upon its removal from the mould. Thus flash removal, polishing, drilling or tapping of holes, gauging, and so on, are matters all of which cannot be arranged with the same degree of flexibility when the designer has to adhere too closely to an existing design not evolved for moulding, than if he is free to work out a design directed towards its mouldability as the prime concern.

This short list here given by no means exhausts the number and variety of advantages possible from adopting such a design angle, but enough has been written to afford ample evidence and guidance to the intending user to enable him to appreciate the value of such a policy as against that usually followed.

Design is Flexible

In conclusion of this portion of article it should be remembered that design is a most pliable and flexible affair, and in the case of nearly every moulding some degree of latitude is permissible in respect of all but the few important characteristics. In some cases wide divergencies from existing shapes and forms would have no disadvantageous effects.

For example, large tracts of the surface area of most mouldings are unimportant in any respect except smoothness, regularity, finish and appearance. Only a few regions are to be treated as vital in respect of dimensional accuracy or duplication, strength, exact shape, and so on.

It is claimed by the writer that the best benefits of plastic moulding will be achieved by such a policy as outlined above. It may mean that a prospective user would be well advised when making initial contact with the moulding manufacturer, asking his advice, help and price for manufacturing a certain moulding, not to submit a sample or drawing of the type of component being used by him but made by a different process and in other materials. Instead, perhaps the best course, looked at from the development of best design, would be to submit a general picture of the purposes, function and features required of the proposed plastic moulding, thus enabling the moulding designer to commence his activities clear of any restrictions imposed, either consciously or unconsciously by the sight and handling of a familiar casting or part it is desired to substitute.

Thus the moulder would be better placed for evolving a satisfactory design more closely fulfilling requirements.

Such a method of design development is retarded, one fears, because users and prospective users, and unfortunately in some cases manufacturers, have insufficient confidence in plastic products as to embark upon entirely original designs.

Furthermore, the art of designing for plastic moulding as such is not yet applied in thorough-going fashion, or in fact seriously studied and its advantages realized in some circles, with the result that reliance is all too often made upon the design policy involving merely the reproduction of design forms of an existing sample article in non-plastic substance.

In a second portion of this article the writer will endeavour to indicate several important design factors, together with illustrations of their practical value in promoting economical production, which will assist, it is hoped, towards improved designs and more nearly perfect products.

Wear Test on Gears

Concluding a Summary of the Investigations of Opitz and Reese ("Kunststoffe," 1942/32/263) and Ulrich and Müller ("Kunststoffe," 1942/32/270) on Plastic Gears (see "Plastics," 1943/7/562)

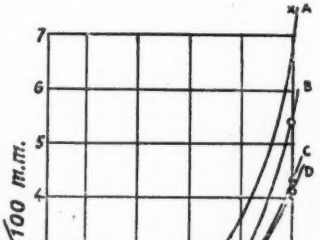

Fig. 8.—Wear in plastic gears of pitch-circle diameter 195 mm. (grease lubrication). Circumferential load 50 kg. per cm. tooth width. Figures above modulus values refer to number of teeth on the gears examined. Curve A—coarse textile laminate II; curve B—fine textile laminate III; curve C—coarse textile laminate I; curve D—laminated wood. Solid lines—pitch-circle velocity 9 m./sec.; broken lines—4.5 m./sec.

IN order to explain the unfavourable influence of a high modulus and a large number of teeth on the wear resistance of plastic gears operating at high speed, it is necessary to examine the relative movement along the flanks of involute gears. (See bibliography.) The rubbing speed between the two flanks lies in the direction of the tangent, becomes zero on the rolling or pitch line, and increases proportionally from this position. It ceases when the two flanks come out of contact. In the case of the gears examined, and with the circumferential speeds selected, there occur the following maximum rubbing speeds (ft./min.):—

Table 7.—Maximum Rubbing Speeds.

Modulus	Pitch circle velocity in ft./min.			
	351	890	1,780	2,370
3	77	196	390	520
5	113	282	565	751
7	150	376	750	1,000

The maximum rubbing speed between the flanks increases with the modulus and is about twice as high for modulus 7 as for modulus 3. Thus the relation between wear and modulus is really a relation between wear and rubbing speed.

Besides a sliding motion along the gear flanks, a rolling movement with a speed v_r is present, this being zero at the end and the beginning of contact, with its maximum at the rolling point (usually on pitch line). Furthermore, the number of teeth gives a measure of contact ratio.

For moduli 3 and 5 two pairs of teeth are always in contact, whereas for modulus 7 only one pair of gears is always in contact, and for 86 per cent. of the length of contact another pair comes into contact. The field in which only one pair is in contact is near the rolling circle, and the pressure between the gears corresponds to the full circumferential load. With $\varepsilon \geq 2$, the circumferential load is distributed over two pairs of teeth.

The maximum surface pressure between the flanks can be calculated by means of the Hertzian equation. According to this, the maximum possible number of teeth is desired in order to limit surface pressure to permissible values. Thus, for high-

speed gears, the minimum number of teeth should be 40, corresponding to a length of contact of $\varepsilon = 2$.

The following conclusion can be drawn: The wear increases with the modulus because (1) maximum rubbing speed between the flanks increases with the modulus, and (2) for a constant wheel diameter, the length of contact becomes smaller with increasing modulus and the surface pressure increases considerably at the top and bottom of the tooth and at the rolling point.

In service, absolute wear will not always be decisive; relative wear may be of main interest, as the clearance between the flank usually increases with the thickness of the tooth. For the same absolute wear, smaller teeth will deteriorate specifically quicker than larger teeth with their greater mass. Therefore, if wear be considered in relation to the original thickness of the tooth at the pitch line, and if this be introduced in a diagram in relation to modulus and number of teeth, the following results are obtained. For low speeds (890 ft./min.) with increasing modulus and reduced number of teeth, relative wear drops, and for high speeds (1,780 ft./min.) for modulus 5 and number of teeth 39, a minimum of relative wear is observable.

This demonstrates, again, that, for low speeds a wheel with high modulus and small number of teeth, and for high speeds, a wheel with at least 39 teeth, give optimum results. These results are in good conformity with theoretical considerations. It would be interesting to know whether, with a further increase in speed, optimum wear lies still in the range of 39 teeth and a contact ratio of $\varepsilon = 1.98$, or whether it moves into the range of higher speeds.

Investigation of Tooth Flank Surfaces

For a complete assessment of the wear of gears the measurement of the flanks by means of an involute tester is absolutely necessary, as this gives a true picture of the course of wear over the whole flank. In order to study the influences discussed in the previous section, from each wheel numerous involute diagrams were taken, which show directly the size of the roughness of the machining, errors in the teeth and the wear.

From the course of wear on gears (modulus 3, 65 teeth), shown in Fig. 8, it is evident that, after a few hours' running, smoothing of the flanks takes

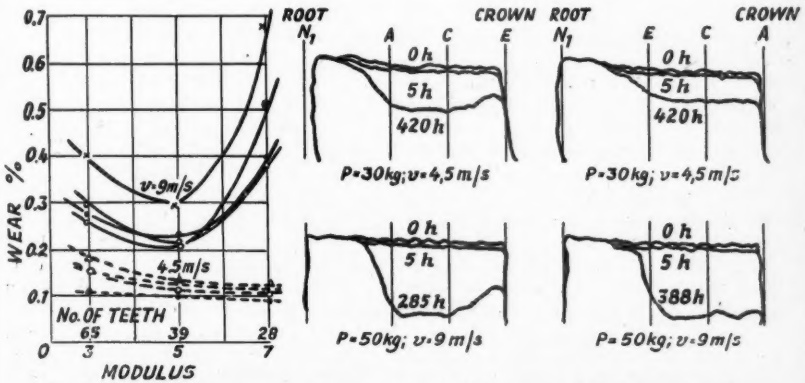

Fig. 9 (left).—Percentage wear referred to tooth thickness on pitch-line circle. Data as in Fig. 8. Fig. 10 (group at right).—Four involute diagrams for laminated gears of modulus 3, 65 teeth, pressure angle 15 degrees, contact ratio 2·35; N—beginning of involute, A—beginning of contact, C—rolling point, E—end of contact. Upper and lower diagrams at left of group—driving gears; diagrams at right of group—driven gears.

place. Later on, wear occurs at the driving wheel owing to the scraping action of the top flank of the driven cast-iron gear. This wear is distributed almost uniformly over the whole tooth flank towards the top; at this point, wear is somewhat lower.

Illustrations at the right-hand side of Fig. 8 show driven gears in which contact starts at the top. Wear runs uniformly

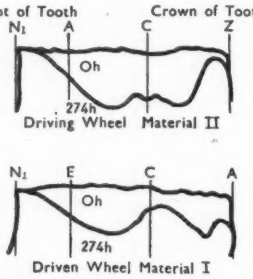

Fig. 11.—Involute diagrams of laminated gears, modulus 3, 39 teeth, pressure angle 15 degs., contact ratio 1.98. Data as in Fig. 10.

over the whole length of flank, starting from the top, until the end of the contact. The other illustrations comprised under Fig. 8 are involute diagrams of gears running under high load. They show very clearly that the top of the teeth of the driving gear exhibits less wear. The following explanation of this is given in the original text. With a contact ratio of 2.35, not less than three pairs of teeth are already in contact when contact is established between a further pair. The point of contact of the first pair is at the top of a tooth, that of the second pair on the pitch line, and that of the third pair at the bottom. This means that the load is, at this moment, distributed over three gears, and it is probably taken mainly by the third and second pairs. Owing to the flexibility of the laminated material, distinct deflection is possible.

Involute diagrams of gears of modulus 5, 39 teeth, have an absolutely different appearance. For low loads, a certain smoothing of the surface and low wear over the whole flank at first occurs. If, however, the load be increased, the wear appears. In the case of the driving wheel, the wear at the bottom zone starts where the contact occurs. Owing to a reduced contact ratio of 1.98, at the moment when a new pair of teeth engage, the previous pair is in the rolling circle range, and, owing to the low sliding speed in this zone, wear due to this remains small, but, through rolling friction, and the momentary increase in surface pressure, when only one pair is in contact, as well as the reversal of rubbing speed at the pitch line, a linear marking is produced at the flank. The counter flank of the new pair of teeth cannot be exposed to such a wear, as the circumferential load is taken up by the previous tooth in the rolling circle which has not been subjected to much wear. If the teeth rotate further, they come into contact with the portion of greater rubbing speed, thus causing increased wear. Furthermore, when the top of one tooth makes contact only a

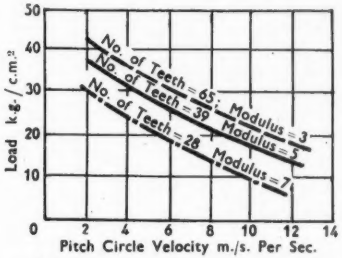

Fig. 12.—Stress factor (c) for laminated gears, moduli 3, 5 and 7; number of teeth, 65, 39 and 28.

slight load has to be transmitted, this resulting in low wear. After a longer period of running, the wear zone at the bottom of the tooth is widened for both driving and driven teeth, extending in direction towards the bottom of the tooth.

Wear at the top of a driving gear is again somewhat less than that of a driven gear. The course of wear along the flank of gears of modulus 7 (28 teeth) does not show any remarkable difference from that of a gear of modulus 5 (39 teeth).

Summarizing the results obtained by

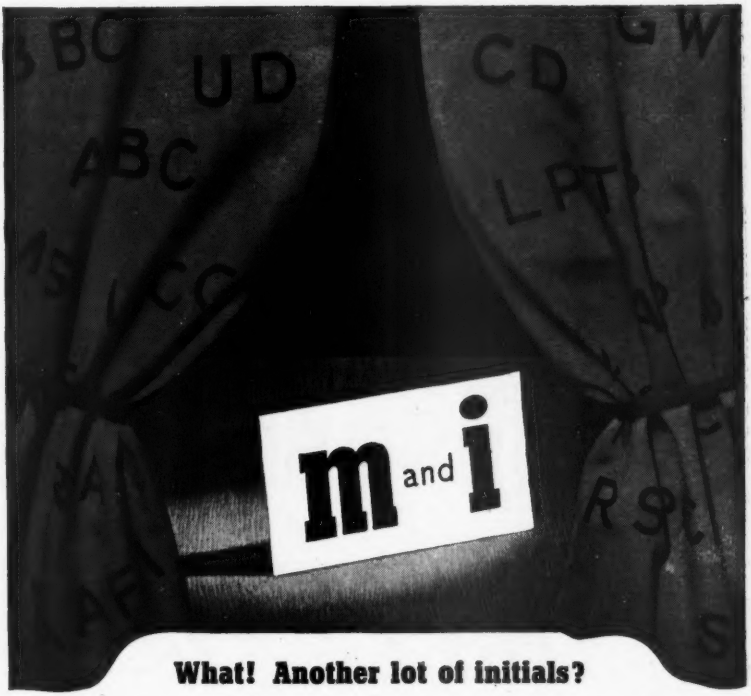

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Table 8.—Values for the additional factor c_1.
(For numbers of teeth below 39 it is negative, above 39 positive.)

Number of teeth	24	25	26	27	28	29	30	32	34
c_1 (kg./sq. cm.)	−14.1	−12.1	−10.3	−8.8	−7.5	−6.4	−5.4	−3.8	−2.5
Number of teeth	36	39	—	42	45	48	50	52	55
c_1 (kg./sq. cm.)	−1.4	0	—	1	1.9	2.6	3.0	3.3	3.8
Number of teeth	58	61	—	65	70	75	—	—	—
c_1 (kg./sq. cm.)	4.2	4.6	—	5.0	5.4	5.8	—	—	—

means of the involute diagrams, it can be stated that wear is mainly caused by sliding friction at the middle of the top and bottom of the teeth. The rolling friction, having its maximum of the pitch line, has no influence so long as the load is not high and the contact ratio is ≦ 2.

Calculations for Laminated Gears

Assuming that wear is a function of both speed and load, opportunity is given to make recommendations for the calculation of the dimensions of laminated gears when pitch diameter and a distinct life are given. The "life" limit depends on the service demanded. Whereas in gears not subjected to shock loads, the wheels can run until they become useless, in the case of shock loads wear should not be allowed to proceed too far owing to the necessary safety allowance for tooth breakage. If the gears run with a shockless load, data should be calculated for wear only.

As limit for the useful life of laminated gears, a period was selected at the end of which tooth thickness at the pitch line was reduced by 10 per cent. For gears running for short periods only, and for partly loaded gears in general, the life was assumed to be 5,000 hours. Into this category fall driving gears, layshaft gears, and change-speed gears for machine tools and hoisting machinery.

For the calculation of gears the usual formulæ are based on the bending stress,

$$\frac{P}{b} = c.t. = c.m.\pi$$

with P = tangential load (kg.), b = width of tooth (cm.), t = m. π = circular pitch (cm.) and m. = metric modulus; c (kg./sq. cm.) is a load factor[1], not considered now to be a constant for a distinct material, but to be further dependent on peripheral speed and number of teeth.

Based on the wear-speed and wear-load curves already discussed, suitable c-values have been determined. The speed range investigated was from about 600 to 2,400 ft./min. The curves obtained were of a hyperbolic character.

As gears with 40 teeth and a "contact ratio" of 2 (or, more accurately, 39 teeth with a ratio of 1.98) show low wear, the lowest c-curve was selected according to the empirical law

$$c_0 = \frac{1000}{v + 14.6} - 23.2 \text{ (kg./sq. cm.)}$$

with v = peripheral speed in m./sec. This formula can be assumed to be valid for all materials, but for any other number of teeth, a correcting factor c has to be used, giving $c = c_0 + c_1$, where c_1 accounts for the modulus and number of teeth according to Table 8.

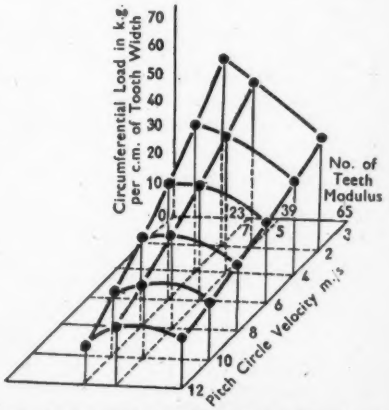


Fig. 13.—Permissible circumferential load in kg. per cm. of tooth width, in relationship to pitch-line velocity and number of teeth. Pitch dia., 195 mm. Life of gears, 5,000 hours.

[1] The formulæ used in England and America are similar, but the factor $c = c_1, c_2, c_3, c_4$ is already composed of several factors embracing tooth form, strength, bending stress, speed, and, of course, a conversion factor.

BRITISH PATENT ABSTRACTS

557,323. **Application:** **13.4.43.** **Granted:** **16.11.43.** Improvements in and relating to Adhesive Fabrics. A. P. Shaw.

A method of manufacturing self-adhesive surgical bandages consisting of coating or spraying a continuous length of textile gauze fabric with a thermoplastic resin, such as Gelva No. 7, in carbon tetrachloride with dibutylphthalate as plasticizer, driving off the solvent by partial drying, so as to leave the resin and plasticizer finely distributed over the meshes of the fabric.

557,324. **Application:** **5.3.43.** **Granted:** **16.11.43.** Improvements in the Production of Cellulose from Ligno-Cellulose Material. H. Dreyfus.

Cellulose is produced from ligno-cellulosic materials such as straw or poplar sawdust by heating such materials after they have been delignified, in a dilute aqueous solution of an acid, other than nitric and nitrous acids, treating the materials with an alkaline solution to dissolve hemicelluloses, and then removing the alkaline solution containing the hemicelluloses from the materials.

557,345. **Application:** **11.5.41.** **Granted:** **16.11.43.** Improvements relating to Moulding Plastic Materials. J. H. Goode.

A mould is described in which a longitudinal split liner is used to form the bore of the mould which contains the dies and within which the articles are formed by the applied pressure. The liner facilitates the removal and separation of the dies.

557,364. **Application:** **24.3.43.** **Granted:** **18.11.43.** A Process for the Manufacture of Resinous Condensation Products. Beck, Koller and Co. (England) Ltd.

A process for the manufacture of clear, stable, water-white hydrocarbon-soluble rapidly heat-convertible etherified urea-formaldehyde resinous condensation products, which comprises heating one mol of urea with 2.0 to 2.3 mols of aqueous formaldehyde at a pH between 8.0 and 9.0 in the presence of an alkaline reacting catalyst subjecting the mass to a distillation under vacuum equivalent to a pressure of 30 to 100 mms. Hg. until 65 to 100 per cent. of water originally contained in the formaldehyde is removed, heating the resultant intermediate resinous mass with an excess of the monohydric alcohol in the presence of an acidic catalyst at a pH of between 5.5 and 6.0, subjecting the resinous mass to distillation under vacuum equivalent to a pressure of 30 mms. Hg. or more, until the resulting resinous mass will tolerate 10 to 50 ccs. of straight chain hydrocarbons per 10 grams of resin.

557,451. **Application:** **17.4.41.** **Granted:** **22.11.43.** Improvements in and relating to Phenol - Aldehyde Resinous Condensates and Compositions. British Thomson Houston Co. Ltd.

A method of making phenolic condensation products comprising two stages in the first of which a lignin is dissolved in a phenol and reacted with at least one aldehyde in the proportion of from 0.5 to 0.95 mol per mol of phenol and under acid conditions, while the second step consists of converting the reaction mixture to alkaline conditions and reacting the alkaline mass so formed with additional aldehyde in an amount such that the total aldehyde content is about 1.2 to 1.5 mols per mol of phenol.

Part of the aldehyde in the second reaction may be converted to a nitrogen-containing derivative by the use of ammonia of primary or secondary amines. The use of dispersing agents is also claimed.

557,473. **Application:** **18.8.42.** **Granted:** **22.11.43.** Improvements in Manufacture of Surgical Adhesive Dressings. A. de St. Lamas and Co. Ltd. and S. W. Atherley.

Surgical dressings comprising a film of polymerizate of acrylic acid or vinyl alcohol, with a coating of adhesive applied thereto, together with modifications of the method of production and application to gauze, etc., are described in B.P. 427,491, 441,988 and 448,164, but the present patent claims that it is an improvement to replace the acrylic or vinyl resin by a suitably plasticized resin of the acetal type, e.g., polyvinyl acetate hydrolyzed and reacted with formaldehyde such as is supplied under the trade mark "Formar."

PRODUCTION NEWS

Raw Materials, New Plant, Works Organization, Control Apparatus, Research, Personal and Trade Notes

ENGINEERS EXCHANGE IDEAS.—An interesting development to enable foremen who are normally confined to their own workshops to see and get accustomed to the processes of other firms so that anything they learn can be applied to their own works, was inaugurated last month by the Ministry of Production. It is noteworthy that the first works to be visited was that of Ray Engineering Co., Ltd., the well-known plastic moulding concern of Bristol. The visitors were foremen from six Bristol engineering works and they were shown not only plastic moulding, but also the production of the tools for high precision work.

MACHINES FOR THE PLASTICS INDUSTRY.—An association has been formed by T. H. and J. Daniels, Ltd., Stroud, Francis Shaw and Co., Ltd., Manchester, and Alfred Herbert, Ltd., Coventry, for the development and manufacture and sale of a comprehensive range of machines and equipment for the plastics industry.

By arrangement with the Reed-Prentice Corporation of Worcester, Mass., U.S.A., the complete range of their injection moulding machines will be made in this country by the new association.

Broadly speaking, the division of manufacture and selling activities will be as follows:—

Moulding presses up to 250 tons, preforming machines, injection moulding machines up to 8 oz. capacity, hydraulic pumps, preheating ovens and hydraulic valves will be made by T. H. and J. Daniels, Ltd.

Extruding machines, presses larger than 250 tons, mixing and calendering machines and large injection moulding machines up to 22 oz. capacity will be made by Francis Shaw and Co., Ltd.

The sale and servicing of these machines and the supply of dies and moulds will be undertaken by Alfred Herbert, Ltd.

A full range of die- and mould-making plant will be offered.

INSTITUTE OF THE PLASTICS INDUSTRY.—At a recent meeting in Newcastle, representatives of several plastic manufacturing concerns decided to form a North-Eastern Branch of the Institute. Mr. W. J. Brown, M.I.E.E., who presided at the meeting, has been elected chairman of the new branch.

EDUCATION.—A course of educational classes in plastics has commenced at East Ham Technical College. They are held on Tuesdays from 7 p.m. to 9 p.m. and are of a general nature, but special attention is being paid to manipulation. The course of lectures is being given by R. R. Rolles, B.Sc.

BOWDLER AND BICKERDIKE, Eagle Chemical Works, Church, Lancs, announce the retirement of Mr. R. B. Bickerdike after 38 years in the chemical trade. The remaining partner, Mr. H. E. J. Cory, continues the business as sole proprietor. The firm manufacture a range of chlorinated phenols, preservatives, anti-mould and anti-mildew compounds, suitable for a variety of purposes. Mr. Cory will continue from the same address his separate business as merchant and exporter of dyes and specialized chemicals, in addition to maintaining his consulting practice.

CASEIN PLASTIC ASSOCIATION.—We have been informed that the group of manufacturers, hitherto known as the Artificial Horn Manufacturers Association, has changed its name to the Casein Plastic Association.

STEELE AND COWLISHAW.—As from January 1, 1944, the style of the above firm will be altered to Steele and Cowlishaw, Ltd.

CHANGE OF ADDRESS.—Mr. H. Landsberger has changed his address to:—189-190 High Holborn, London, W.C.1. (Phone, Holborn 7878.)

INDEX FOR "PLASTICS."—Copies of the index to Vol. VII of "Plastics" are now available from this office, price 7d. post free.

BRITISH INDUSTRIAL PLASTICS, LTD.—Gross profits of £327,852, a new high level for the company, have been recorded in the preliminary statement for the year to September 30, 1944. The net profit is £21,659.

Resinoids and Other Plastics as Film Formers

By B. J. BRAJNIKOFF,
Consulting Electrical Engineer

XXIII.—Coating Media on Vinyl Acetate and Polyvinyl Alcohol Base

THE recent years have witnessed a very rapid rise to prominence in the plastics industry generally, and in coating technology in particular, of two types of synthetics, viz., those derived from the polymerized vinyl acetate and polyvinyl alcohol. The technical significance of vinyl acetates may be gauged from the fact that, either by the direct autopolymerization, or by combining with the various members of polyvinyl esters, such as polyvinyl halides (viz., vinyl chloride, vinyl bromide), or acrylic acid esters, as well as maleic esters, etc., they readily form almost endless series of co-polymers, which, in addition to use as pressure and injection-moulding powders, yield superior film-forming agents, artificial fibres and other products.[328]

Vinyl acetate was discovered by Klatte in 1913, who obtained it by the reaction of acetic acid and acetylene in the presence of a catalyst: $CH_3COOH + CH \equiv CH \longrightarrow CH_2 = CHOCOCH_3$. The same investigator was also the first to prepare polyvinyl acetate: $— CH_2 — CH(OCOCH_3) — CH_2 — CH(OCOCH_3) — CH_2 —$, by subjecting the vinyl acetate to the action of light, as described in the original patent specifications granted to the Chemische Fabrik Griesheim-Elektron.[329]

Polyvinyl alcohol, $— CH_2 — CHOH — CH_2 — CHOH — CH_2 — CHOH —$, is formed as a result of the hydrolysis of polyvinyl acetate (Hermann and Haehnel).[330] At ordinary temperatures the polyvinyl alcohol is solid, but on warming it displays rubber-like properties and may be utilized for the production of highly elastic tubing, or as lining for containers, strongly resistant to organic solvents (e.g., benzene, oil and alcohol). It is equally suited for the manufacture of films, threads and other compositions of outstanding merit for applications in impregnating and coating technique, etc., as testified lately by the profusion of patents. The most noteworthy work has been achieved by du Pont de Nemours[331] in the U.S.A.

Owing to its ability of forming a vast range of compounds through its combination with aldehydes and ketones, classed under the general term of acetals, polyvinyl alcohol enormously increases this prolific source of synthetics. Moreover, the diversity of these derivatives may be extended still further by utilizing polyvinyl ethers,

$$— CH_2 — CHOX — CH_2 — CHOX — CH_2 — CHOX —,$$

(where X stands for any radical), which are obtainable through polymerization of vinyl ethers by the method evolved by I.G. Farbenindustrie.[332]

By virtue of the ability to form latex-like systems, co-polymers of vinyl ethers are of great commercial importance, constantly expanding the scope of their applications to the production of superior impregnants, adhesives and varnishes.[333]

From the survey of high-elastic deformation in polymers presented in the preceding section, it may readily be appreciated that its data will be found of considerable help in appraising the value of products derived from polymerized vinyl acetate and polyvinyl alcohol as is given in the subsequent text. The method of treatment will follow closely the plan adopted in Section VI of this work dealing with the role of polyvinyl chloride resins in surface coatings, presenting a

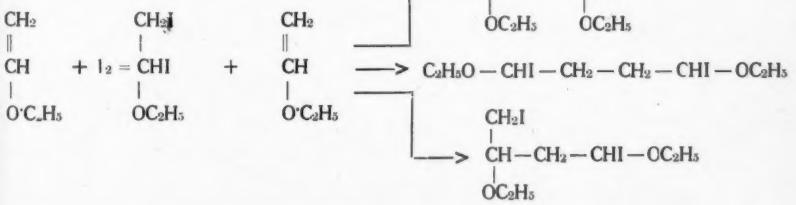
brief but a comprehensive and systematic account of the part these valuable elastomers play in coating media, the latest trend in their development, and their potentialities in the world of industry.

Early Development

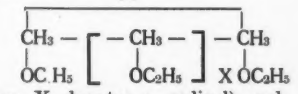
It has been known for a long time that haloid derivatives of ethylene or the ethers of the vinyl alcohol possess a strongly pronounced tendency to polymerize. In 1878, Vislizenus,[334] by subjecting vinylethyl ether, $CH_2 = CH\text{-}O.C._2H_5$, to the action of iodine, had obtained its polymer. In this reaction it was found that one part of iodine was capable quantitatively of converting 209 parts of the ether into polymers. In terms of molecules, this means that one molecule of iodine transformed 737 ether molecules into polymers.

This fact, in itself extremely curious from the theoretical standpoint, is the more interesting in that, according to Baumann[335] and Ostromislensky,[336] the iodine impedes the polymerization of vinyl halides by means of light and, as has been found by Ruschinsky,[337] does not promote the polymerization of vinyl acetate. The latter discolours the iodine solution in potassium iodide and reveals no signs of polymerizing. On the other hand, as was shown by Meyer[338] and Stobbe and Färber,[339] indene under these conditions polymerizes readily.

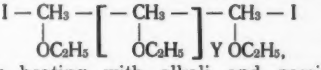
The mechanism of polymer formation Vislizenus had formulated in the following manner:—



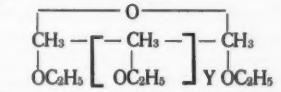
However, the above investigator refrained from suggesting as to which of these three variants belongs the important role of effecting the polymerization process. As the molecules of the vinylethyl ether proceed to accumulate, there are formed polymers of the type:—



(where X denotes a radical) and, as a result, the iodine-containing polymer:—



after heating with alkali and passing into an oxide, yields:—



Thus it is clear that in the light of the foregoing schemes our contemporary notions on the process of the polymerization of olefines and the structure of their polymer appear to be far from new.

Looked at in the past as a curious episode in the general progress of the synthetic chemistry, Vislizenus's polymers acquire at the present time quite a different interest. If the polymerization of the derivatives of ethylene under certain conditions leads to the formation of compounds of the type of a substituted long fatty saturated chain:—

$$—CH_2—CHX—CH_2—CHX—. \; . \; .—CH_2—CHX—CH_2—CHX—,$$

where X signifies any radical, then it follows that polymers of the ethylvinyl ether will be related to polymers of the vinyl acetate in the same genetic way as that of the ethylcellulose to the acetylcellulose, since both polymers of a simple

and compound (complex) ether of vinyl alcohol will be derivatives of one and the same really existent polyvinyl alcohol,[340] in a manner just as ethylcellulose and acetylcellulose are derivatives of the parent cellulose:—

$$—CH_2—CHOH—CH_2CHOH—. \ . \ . \ .$$
$$CH_2—CHOH—CH_2—CHOH—$$

Polyvinyl alcohol

Undoubtedly, the conditions of polymerization must exert an influence on the structure of a resin, and polymers of similar substances, generally speaking, may be considered as analogous in their structure only in the event that they have been obtained under identical conditions. Hence; the polymerization under dissimilar operational conditions may lead to the production of polymers differing in their structure.

Ostromislensky[341] in his extensive researches in 1912, has made an attempt to establish connection between polymers of vinyl halides, termed by him cuprenechloride and cuprenebromide, to which he assigned the structure

$$\begin{array}{l} CH_2-CHCl-CH_2-\ldots.-CHCl-CH_2-CHCl-CH_2 \\ \quad | \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad | \\ CHCl-CH_2-CHCl-\ldots.-CH_2-CHCl-CH_2-CHCl \end{array} \quad \text{or} \quad [-CH_2-CHCl-]_{16}$$

and the higher chloride of erythrene rubber:

$$\begin{array}{l} CH_2-CHCl-CHCl-CH_2-\ldots.-CH_2-CHCl-CHCl-CH_2 \\ \quad | \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad | \\ CH_2-CHCl-CHCl-CH_2-\ldots.-CH_2-CHCl-CHCl-CH_2, \end{array}$$

considering them as isomers; the first—as a symmetric chloride, and the second—as unsymmetric chloride of hydrogenated erythrene rubber.

At about the same time the German Chemische Fabrik Griesheim-Elektron[342] developed the method for the production of vinyl ethers of organic acids through the addition of the latter to acetylene. As regards the vinyl acetate, the Griesheim-Elektron process had subsequently undergone various modifications, which formed at a later period the subject-matter of a series of patent specifications.[343]

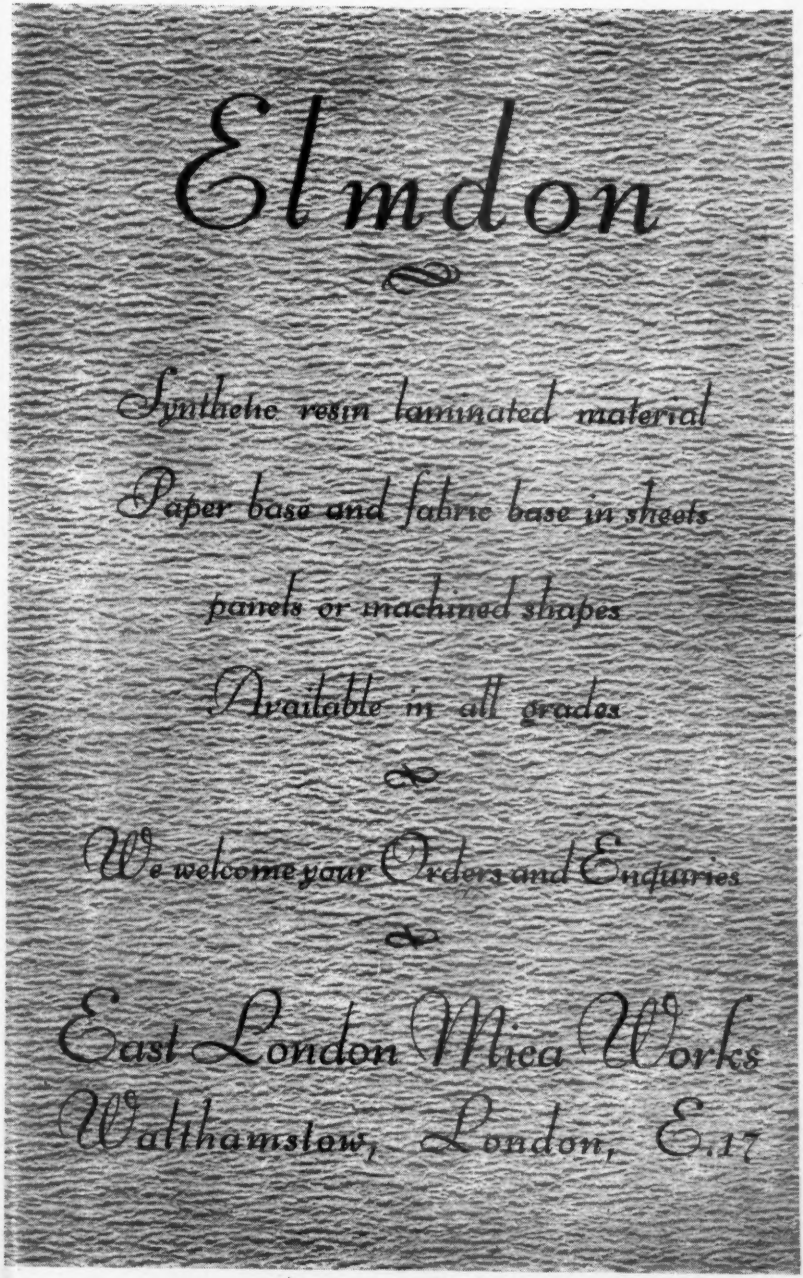
The vinyl acetate, for the synthesis of which serves the same abundant raw material, cheap acetylene base, has, naturally, become the subject of special attention. The quality of the resins derived from it immediately placed the latter into the range of the compounds for which there exists a vigorous demand in the coating technology and the plastics industry. Of course, as it is to be expected in such an event, soon there was no lack of methods for its polymerization,[344] as shown by voluminous patents.

Polymerization Methods

The polymerization of vinyl acetate can be promoted either (i) by the action of light, or (ii) by heating in a hermetically sealed vessel, or (iii) under the influence of chemical reagents.

These methods, with exception of the latter, have been extensively described in the patent literature, but none of them offered the solution of the problem from the standpoint of the industrial manufacture of polymers required for coating media, particularly for high-grade varnishes and lacquers, for the resins produced according to the above patent specifications were either difficultly soluble, or coloured, brittle and fusible.[345]

In the thermal polymerization of vinyl acetate at 110 degrees C. in the absence of air the yield of the resin does not exceed 40 per cent. of the theoretically possible, and in this reaction, apparently, there occur no traces of formation of the initial stages of the polymerization, as dimer or trimer groups, at least in appreciable quantities. The mechanism of the thermal polymerization of vinyl acetate is still in the stage of investigation, and the information available in the literature is of the fragmentary nature. One of the aggravating facts in the polymerization by heat is that the resin formed during the process contains a certain amount of non-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reacted matter, which even at 200 degrees C. shows no signs of volatilization; it merely yellows gradually, softens into a viscous mass, without, however, melting and dropping at the bottom of the tube. It was found, however, by Ruschinsky[337] that, since the volatile inclusions can be readily expelled by distillation, the unreacted substances can be got rid of and the resin purified by resorting to appropriate distilling operation. The resin obtained in these conditions is almost colourless, with a slight greenish-yellow tinge, transparent, elastic, and its solution in the organic solvents, such as acetone, benzene or chloroform, leaves a resinous layer on the mercury surface in the form of a transparent, colourless, flexible film, retaining elasticity at ordinary temperature for a long time; dried at 100 degrees C., the resinous film becomes more brittle. By liberating the resin from acetone solution by water, and from the chloroform solution by petroleum ether, there are obtained soft, elastic masses, returning after stretching to the original size, of which the product that has been released from acetone, after a prolonged keeping in the desiccator over the sulphuric acid, more rapidly lost the said properties and could be ruptured. With a certain degree of dexterity, it is quite possible to blow a sphere from a very strong solution of the vinyl acetate resin.

The thermal polymerization of vinyl acetate can be effected both in the presence or in the absence of chemical reagents, which include also the oxygen of air. It has been established that active oxygen, as, for example, contained by peroxides or ozone, promotes polymerization and increases the yield of resins. Nevertheless, for excitation of the reaction the primary requisite is the application of heat. However, in this case the produced resins are less soluble in the solvents commonly used in varnish manufacture and therefore are less suitable for the coating media. Ruschinsky,[337] by substituting oxygen for air, obtained on heating at 110 degrees C. a greater yield of resin, whose solubility was still difficult. The same worker, further, proved that polymerization proceeds also in the atmosphere of such an inert gas as carbon dioxide, and, consequently, the presence of oxygen cannot be regarded as the indispensable condition of the possibility of the polymerization by heat. In this event thermal energy serves as exciter of the activity of the double bond. Ruschinsky has found that the yield of resin may be increased up to 80 per cent., by heating the vinyl acetate up to 110 degrees C. with an ordinary sulpho-ether or low-boiling petroleum ether in the presence of air. In the presence of petroleum ether, but in the medium of carbon dioxide, the yield of the resin produced was smaller. In the presence of benzene and chloroform the resinous yield is very low, and in the presence of carbon sulphide it is nil.

Taking into consideration the vapour pressure of these liquids at 110 degrees C., it should be deduced that here we are dealing not only with the increase of pressure, but with the action of a favourable medium as well. The favourable influence of the petroleum ether is also curious in that the presence of this ether during the polymerization of vinyl bromide by means of ultra-violet rays, according to Ostromislensky,[346] prevents its polymerization.

An attempt by Ruschinsky[337] to polymerize vinyl acetate in the cold by saturating it with oxygen, also in the presence of vanadium oxide, has not been successful.

The difficult solubility of the resins obtained in the presence of active oxygen is probably conditioned by the emergence of oxygen-containing polymers, but not by the later stages of polymerization.

The polymerization in the presence of peroxides and ozone should also be included into the thermal polymerization, although ozone acts catalytically and under the condition of illumination, while the benzoyl peroxide is, apparently, acting only on heating.[347]

Taking into account the exothermic nature of the polymerization reaction, the

carrying out of the latter by means of peroxides on a full-scale factory production would be fraught with the hazard of explosion.[348]

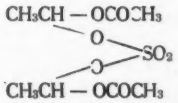
These drawbacks have been effectively surmounted in the polymerization process in the presence of petroleum ether, as found by Ruschinsky.[337] In this case, on account of the insolubility in petroleum ether, the resins are easily released in the procedure; they are perfectly colourless, elastic and, due to their solubility in varnish solvents, are admirably suited for coating compositions.

In the polymerization process by means of sunlight or ultra-violet rays, in the presence of air, it is impossible to prevent the activation or ozonizing of the oxygen of air and, since the information on the action of light in the medium of inert gas is not available, to form the conclusion of that or another action of light would be premature.

In the absence of the systematic data on the velocity of polymerization, the industrial realization of the photochemical method is greatly hampered. With regard to the utility of the process for coating and kindred fields, it may be stated that some of the patent specifications claim that a prolonged illumination by ultra-violet rays leads to the formation of resins, less soluble in alcohol, while in the reverse case (short action of light) the resinous yields are not quantitative.[349]

Recently Medvedeff,[350] who studied the kinetics of the polymerization of vinyl acetate catalyzed by benzoyl peroxide, has found that the resultant complex of vinyl acetate and peroxide with the monomer forms the active centres; the heat of activation for the polymerization is 25,500 cal. per mol.

There is no information in the available literature on the polymerization under the action of chemical reagents in the cold. Ruschinsky[337] has noticed that the vinyl acetate is gradually polymerized in the presence of the anhydrous aluminium chloride, but the resulting resins are of the yellow-brown colour. A drop of concentrated sulphuric acid acts on one mol of the substance far too strongly and yields results which are less characteristic. On agitating, there is observed a slight warming. A drop of moderately strong sulphuric acid acts on the same quantity of substance in a gradually saponifying manner. In both cases the product of the reaction on standing in a sealed test-tube was a solid, porous black mass, which failed to dissolve in common solvents. Simultaneously there is observed a distinct smell of SO_2 and acetic acid, which testifies to the partial saponifying and acidifying of the substance. Since this rate of progress in this conversion is very slow, it follows that in this case there is being formed at first a strong addition-compound, in contradistinction to that observed in indene and other combinations, in which the ethylene bond forms with the substitute either a system of the cross-linking double bonds or a system of conjugated double bonds, which, under the action of minute quantities of strong sulphuric acid, polymerize almost instantly. Whether or not this addition product



condenses further in accordance with the Vislizenus polymerization scheme with the vinyl acetate, it is impossible to say, as the reaction was investigated in greater detail. Theoretically, this condensation is feasible only on the condition of the preliminary dissociation into an acid radical, or, in the case of acid of lesser concentration, at first there proceeds saponification with the formation of the acetic acid and aldehyde.

At this juncture it will be of interest to point out that Ostromislensky,[352] and, prior to him, Baumann,[353] in the process of splitting off HBr from polymers of vinyl bromide, had obtained a black product, which, according to Ostromislensky, has the constitution $(CH)_n$.

The polymers of the vinyl bromide, often slowly in the cold and rapidly on heating up to from 30 degrees to

40 degrees C., go black in colour, simultaneously splitting off HBr. The analysis of such a compound, according to Ostromislensky, indicates the combination, which is inferior in bromine value to that of the cauprenebromide. On precipitating the solution of the black polymer there are formed the colourless flakes.[354]

The vinyl acetate, $CH_2 = CHOCOCH_3$, is hygroscopic and partially soluble in water; dried over calcium chloride, it boils at 72 to 73 degrees C. It adds bromine with the titrometric precision. In the titration with the pure bromine the ether should be diluted a little by chloroform.

(To be cont.nued)

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GERMAN PLASTIC LANTERN

(Continued from p. 65)

this is not clear. The tank is fitted with an inlet for water and a screw control for regulating the delivery of water to the calcium carbide.

Inserted in the top of the spigot is a metal nozzle $\frac{3}{4}$ in. long, at the end of which the acetylene burns. At the base of the spigot on the underside of the projection is a perforated metal screw cap lined with felt, which serves to slow down the flow of acetylene from the generator to the nozzle. Two plastic ridges are moulded on the back of the water tank assembly, but the purpose of these is obscure. A metal clip is fastened between and below these ridges and can be used for securing the lantern to vehicles, etc.

The calcium carbide is stored in a circular plastic cup, the side of which is ribbed. A loose-fitting plastic disc inside the container serves to distribute the water over the carbide, and to prevent frothing. The cup is screwed to the underside of the water tank assembly, and a rubber washer ensures a gas-tight fit.

The plastic components are compression moulded from the German Type T.2 material, which is chopped and macerated fabric-filled high shock resisting phenolic powder. Some blistering has been produced in the dome which is vertically above the flame. The dome had also cracked between the outside and one of the hinge holes.

Our own reaction to this lantern is that from all points of view plastics would seem unsuitable. It will probably be more interesting to the Ministry of Economic Warfare than to plastic moulders.

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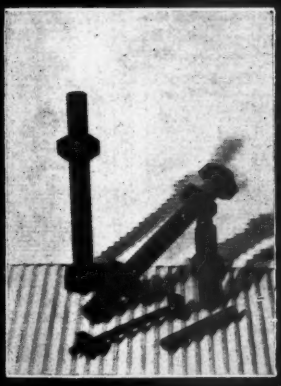

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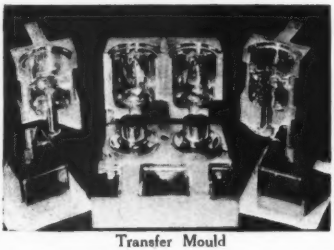

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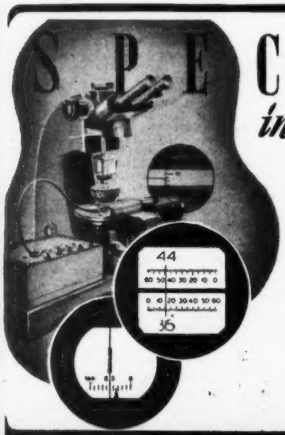

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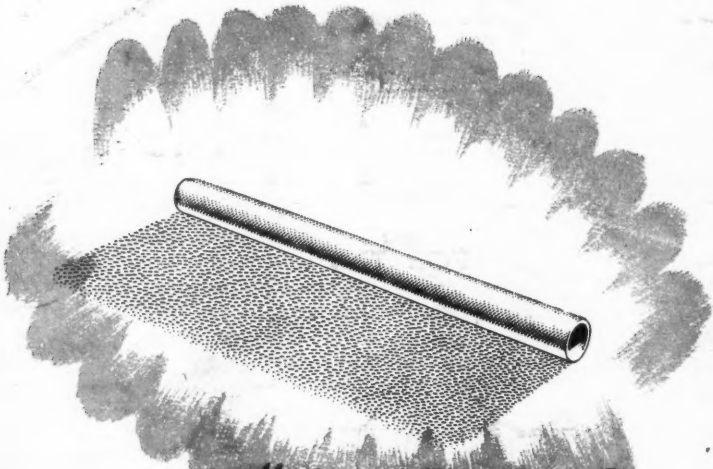

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